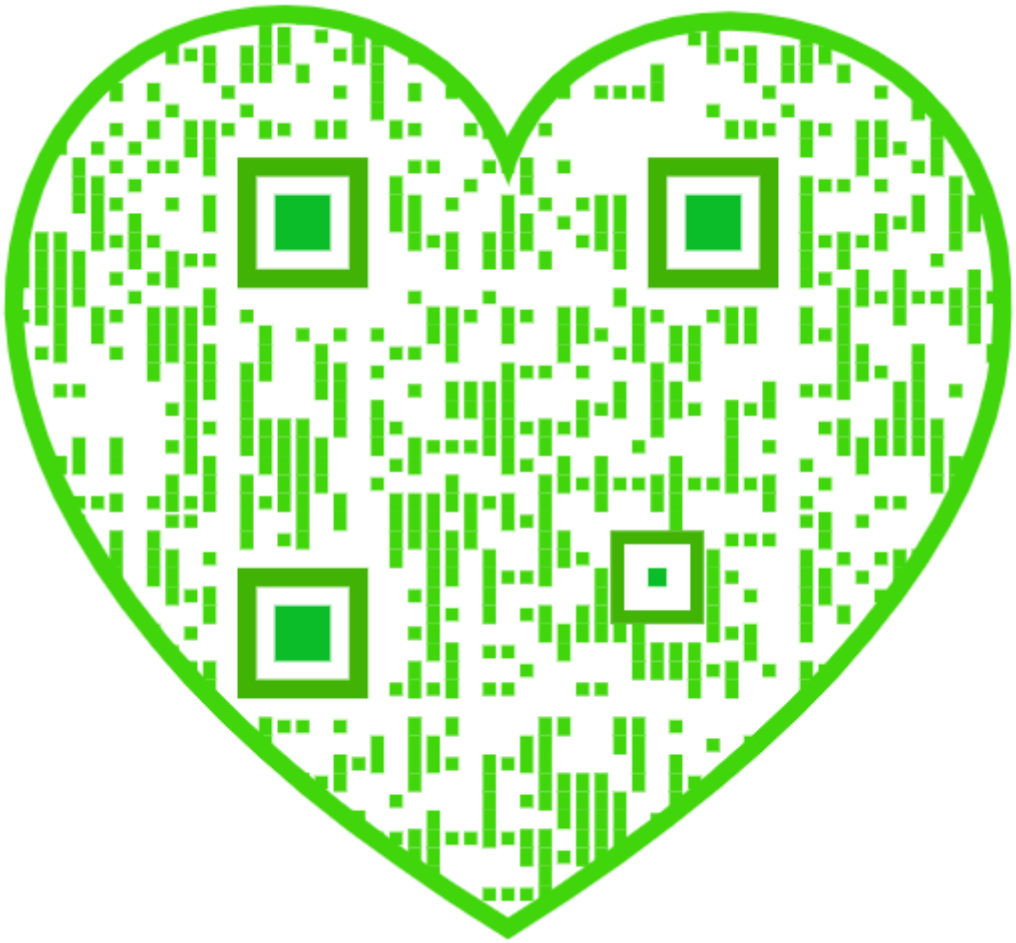

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THE ORIGIN AND RATIONALE

OF

COLLIERY EXPLOSIONS.

FOUNDED UPON

AN EXAMINATION OF THE EXPLOSIONS AT THE

TIMSBURY, ALBION, MALAGO VALE, AND LLANERCH COLLIERIES,

AND UPON THE PRINCIPAL PHENOMENA OF THE DISASTERS AT THE

ABERCARNE, ALLTOFTS, ALTHAM, APEDALE, BLANTYRE, BRYN, CLIFTON HALL, DINAS, ELEMORE, HYDE, LLAN, MARDY, MORFA, MOSSFIELDS, NATIONAL, PENYGRAIG, RISCA, SEAHAM, TRIMDON GRANGE, TUDHOE, UDSTONE, AND WEST STANLEY COLLIERIES.

BY

DONALD M. D. STUART, F.G.S.,

MINING AND CIVIL ENGINEER;

AUTHOR OF "COAL-DUST AN EXPLOSIVE AGENT."

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PREFACE.

THE subject of Colliery Explosions again commands public attention, and proposals have been recently advanced, for strengthening the statutory regulations for the direction and discipline of Mines. The cause of these calamities has been sought with persistence and assiduity: and evidences have been accumulating for an examination of the respective theories of Fire-Damp and Coal-Dust, as the principal agents in Colliery Explosions.

The large explosions have been attributed to the presence of fire-damp, because that gas was known to be normally yielded in the mines; but this conclusion involved the hypothesis of sudden outbursts or accumulations of gas, of which there has rarely been any evidence beyond the fact that an explosion had occurred. The Coal-Dust theory was advanced to account for the disasters, but the absence of an explosion in non-gaseous mines up to 1893, presented a great difficulty to its acceptance, which was emphasized by the last Royal Commission upon Accidents in Mines in their well-known conclusion, that were coal-dust the principal agent in coal-mine explosions, these disasters would be of more than daily occurrence.

The subject received new point and direction in November, 1893, by an explosion at the non-gaseous mines at Camerton, in Somersetshire, which was proved to have been caused by the gases evolved from coal-dust; but it was the only disaster of this character that had occurred in non-gaseous mines, and therefore afforded an insufficient foundation for raising the question, as to what difference existed between explosions in gaseous and non-gaseous mines.

After a lapse of fifteen months, an important development of the question arose in a second explosion in a non-gaseous mine, at Timsbury,

in Somersetshire, and another opportunity was presented for investigating the phenomena of an explosion, not complicated by the presence of fire-damp. This second explosion provided the occasion for reviewing the facts observed, and the thoughts advanced in the Camerton Colliery disaster; and for preparing records of their fundamental features, so that a further effort may be made to elucidate their cause and rationale.

By the courtesy of Mr. F. R. Foot, the Agent and Manager, I was enabled to make several inspections of the Timsbury Collieries shortly after the explosion, and observed the close correspondence of its phenomena with those of the Camerton Colliery Explosion. Further investigation left no room to doubt, that the explanations I advanced of the Camerton Colliery Explosion were confirmed, and that records of the phenomena of the two disasters, would form an important body of evidence, for investigating colliery explosions generally.

After completing these evidences, I compared them with the records of the phenomena of explosions in gaseous mines, and found that there was an identity in their important features, which demanded for its explanation an identical explosive agent; and as the gases that caused the explosions in the non-gaseous mines proved upon investigation to have been derived from coal-dust, it appeared that the gases which caused the explosions in gaseous mines, must have had a similar origin. Upon subjecting this conclusion to fuller examination, it became obvious that fire-damp could not have been appreciably present in the numerous explosions, the records of which I had examined. Having arrived at conclusions of such importance to Colliery enterprise, I am venturing to offer a second work upon the subject of these mining calamities, for the purpose of making known the evidences upon which those conclusions have been reached.

The explosion at the Timsbury Colliery will be first investigated, and the correlation of its phenomena with that observed in the explosion at the Camerton Colliery, established. This body of evidence will then be employed as a foundation for examining the records of explosions in gaseous mines, and for considering the identities in the phenomena of the two classes of explosions.

I have much pleasure in expressing my obligations to the proprietors of the Timsbury Collieries, and to Messrs. Rees-Mogg and Davy, their Solicitors, for the loan of plans and sections of the Mine from which Plate I. has been prepared, and for other information upon the explosion which they placed at my disposal.

DONALD M. D. STUART.

BRISTOL,
August 22nd, 1895.

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INTRODUCTION.

THE accumulating evidence that a calamitous explosion may be brought about by coal-dust without any assistance from fire-damp, has caused much anxiety to obtain an understanding of the circumstances in which such an explosion is originated, and developed through the mine. The explosion in the non-gaseous mines at Camerton, Somersetshire, in November, 1893, marked a new departure in the consideration of the subject, that being the first explosion which had occurred in a mine yielding no fire-damp. Coal-dust was the only substance in the mine from which explosive gases could have been obtained, and that it did undergo distillation, yielding the gases that were exploded, was proved by investigations of the phenomena in the underground workings. This explosion happened under ordinary circumstances, and originated where two men were performing a common operation in shot firing; but the impression appears to have prevailed that it occurred under exceptional conditions, and that for practical purposes it could be disregarded.

The Royal Commission on Explosions from Coal-dust in Mines received voluminous evidence upon the subject, and enquired into the explosion at the Camerton Collieries; but reported in June, 1894, that:—"Coal-dust alone, without the presence of any gas at all, may cause a dangerous explosion if ignited by a blown-out shot or other violent inflammation. To produce such a result, however, the conditions must be exceptional, and are only likely to be produced on rare occasions."[1]

Ten days later a terrible explosion occurred at the Albion Colliery, near Pontypridd. About 1000 miners had a short time

[1] Second Report of the Royal Commission on Explosions from Coal-dust, p. 24.

previously left the workings, and 295 others entered the mine for various duties, 290 of whom perished. The colliery yielded fire-damp, and contained an extensive distribution of coal-dust. Fire-damp and coal-dust were respectively advanced as the principal agents in the disaster; but at the conclusion of the enquiry, the jury were unable to agree as to its place of origin.

Another explosion occurred on February 9th, 1895, at the Timsbury Collieries, Somersetshire, which caused the death of seven men. Its importance to the coal-dust question is the fact that the Collieries were non-gaseous. Although the explosion at the Camerton Colliery was a practical demonstration of disaster produced by gases distilled from coal-dust, the acceptance of the principle that an explosion with coal-dust alone, was a possible occurrence in the ordinary circumstances of a mine, involved conclusions of some moment, that evidence beyond a solitary case of that character was demanded. Suggestions were made that the theories advanced in the investigation of the Camerton Colliery explosion should be subjected to experiment. Experiments, however, in such matters, partake largely of an artificial character, and their results are inadequate to challenge conclusions that have a basis in fact in a colliery explosion; the phenomena of another explosion in a non-gaseous mine was therefore required for the purpose of subjecting these conclusions to further examination. The disaster at the Timsbury Collieries fulfilled this demand, and afforded a second opportunity of investigating an explosion in which coal-dust was the only possible source of the explosive gases.

This explosion also originated in an ordinary operation of shot firing, and under ordinary circumstances. The atmospheric temperature had been very low for some weeks previously, but that was a condition that may be repeated at any time during the winter seasons. It has shown that low external atmospheric temperatures have an important hygroscopic effect upon coal-dust in a mine, the ventilating currents bringing about an evaporation of moisture, and raising it to a favourable condition for the initiation of chemical actions, that end in disaster.

The Author, having examined the collieries after the explosion, now offers the results of his investigations, in the hope that they will contribute to such an understanding of the subject of coal-dust, that must command the unexceptional recognition of its dangers. The calamities that have occurred in the South Wales and South Western districts since his former work on the subject was prepared, provide full evidence that the adoption of remedies and precautions that experience now suggests, would involve an expenditure which risk to life entails as a positive duty, and that can only be described as trifling compared with the value of property destroyed, and the outlays demanded in restoring the workings and appliances of a mine to their normal state.

DESCRIPTION OF THE TIMSBURY COLLIERIES.

THE Timsbury Collieries are situated in the Radstock district, Somersetshire, on the north side of the Mendip Hills, and adjoin the Camerton mines. The New Red Sandstone strata, which is generally found in the district superimposed nonconformably upon the coal measures, also occurs throughout the extensive mineral estate leased to these Collieries, and yields some feeders of water.

The Radstock series of seams are found beneath the New Red Sandstone, with the following section of Coal:—

	Feet.	Inches.
Withy Mills Seam - - - - -	1	4
Great ,, - - - - -	2	1
Top Little ,, - - - -	1	8
Middle ,, - - - - -	1	1
Slyving ,, - - - - -	1	8
Little Slyving ,, - - - -	1	2

These seams are enclosed in hard strata, which has to be largely excavated in constructing roadways from the coal faces to the shafts. Occasionally the roofs of the seams are intersected with cross jointing, which causes the strata to crumble, and they are then secured by brick arches or timber; but except in these local disturbances, very little timber is required.

The water yielded in the New Red Sandstone is secured at a depth of sixty yards, and pumped to the surface, and the coal measures below are comparatively dry. When the roofs of the seams are first broken in constructing the roads, they yield a little water, which is, however, soon evaporated by the air currents, and the workings become generally dry.

Numerous faults intersect the coal measures, causing vertical

displacements, and though the seams retain their positions relatively to each other, their continuity is broken, and numerous areas of coal are formed on different horizontal planes, which have been worked at varying depths from the surface. The faults do not carry water, and are dry on both sides.

The seams are worked on the Long Wall System, and the *débris* yielded along the working faces, and in the construction of the roads, is employed in filling up the space formerly occupied by the coal, but it cannot be wholly disposed of in this way. Occasionally the *débris* yielded by the Great Seam does not fill the empty space, and at other times it is more than enough for that purpose, and the surplus has to be conveyed to the surface. In the other seams the goaves are filled, and a quantity of *débris* remains, which has to be removed out of the mine. The floors and roofs of the seams are separated by so small a section of coal, that they would soon close together by the weight of the superincumbent strata, even if left unfilled, after the extraction of the coal; but the goaves are filled with *débris*, and become practically solid under the enormous weight of strata that settles down upon them. Some of the roads, however, that are not within reach for filling up with the surplus *débris*, may remain open for some time where the roof is strong, and the side walls are not crushed or displaced; but with these exceptions, there can be no open spaces in the goaves to allow accumulations of gases. The manner in which the continuity of the seams is broken by elevations and depressions, divides the coal into limited areas; the goaves are consequently of correspondingly small extent, and are separated by being on diverse horizontal planes, with the result that there is no extensive tract of single goaf, which, if unclosed, could form an empty space of magnitude for gases to accumulate in.

The Collieries have been in operation for about seventy years, and have always been worked by open lights. In the extraction of the coal, fire-damp has never been discovered in the coal faces, or at the faults that circumscribed them, or in piercing the faults

to reach the seams on the planes to which they had been displaced, or in the intervening strata.

In the method of working, the roads are in the goaves, and in some places coterminous with and near the faults. The stall roads are not filled up with *débris* so as to be gas tight upon their abandonment, and during the period occupied by the roof in its subsidence upon the goaves, any fire-damp in the strata or faults, not previously set free, would now be released by this more extensive movement of the superincumbent strata, and escape through the abandoned roads, and diffuse in the air of the travelling roads. The velocity of diffusion of gases being inversely proportional to the square roots of their densities, and the relative densities of air and fire-damp being 1 and ·559, the latter would rapidly diffuse out through open spaces into the air of the travelling roads, and inevitably have been detected at the numerous open lights constantly passing, and distributed in the workings.

The coal measures being hermetically sealed by the nonconformable New Red formation, their contained gases could find no escape, except through the workings of the mines. These workings have penetrated the measures over extensive areas, and at many horizontal planes; and during the seventy years they have been in operation, contingencies must have arisen on a great many occasions very favourable for the discovery of fire-damp. The air currents swept the exposed sides of the goaves, the faults, and the coal faces: and naked lights were burning throughout the workings; but fire-damp has never been detected, and the conclusion that they are free from that gas becomes irresistible. The Timsbury Collieries therefore belong to the non-gaseous mines; and it is absolutely beyond question that the volumes of explosive gas that were obviously present in the workings to effect such widespread disaster, could have had no origin except in the coal-dust, which was everywhere present.

The workings of the Collieries extend over a considerable area, but for the purposes of this investigation it is only necessary to consider the portions that betrayed evidence of the disaster. The description of these parts will be readily followed if Plate I. be extended during the

perusal; and, commencing at Lower Conygre Colliery, the road or communication can be traced direct to Upper Conygre Colliery, with the branch districts that emanated from it at various points. This communication commences at the Lower Conygre shafts, in the Top Little Seam, at a depth of 332 yards, and proceeds towards Upper Conygre for about 120 yards, where a fault is crossed, displacing the seam downwards twenty-eight yards, and bringing the Great Seam from its normal position above, down to the plane of the road. The road then continues in the Great Seam for about 160 yards (the shot was fired in this part of the road on the night of the disaster), where about thirty-four acres of coal were worked some thirty-six years ago. At the end of the 160 yards another fault is crossed, displacing the Great Seam upwards 140 yards, and bringing the Slyving Seam from its position below, up to the level of the road. This fault changes the strike of the seams, and causes the Slyving Seam to incline upwards in the line of communication, so that to maintain the necessary direction, the road becomes an inclined plane, rising at the inclination of the seam for about 130 yards, and is called Peter's Incline. The communication then proceeds upon its ordinary level for about 350 yards, partly in the Slyving Seam, and partly in argillaceous strata, to another fault, which brings the Little Slyving Seam up to this plane: and the road continues about 260 yards in that seam, entering the Upper Conygre Shaft at the 342 yard level. About twenty yards from the last named fault, there is a junction with Gullick's Incline; at 150 yards, the stables; at 220 yards, junctions with workings upon the seam, and with Upper Conygre Downcast Shaft. The various working districts branch off the communication at various points between the Lower and Upper Conygre Shafts.

Near the top of Peter's Incline an inclined plane, called Wyatt's Incline, is driven up across the strike of the strata to the Top Little Seam, and a road, termed Parfitt's Level, is made in that Seam to the coal face. About seventy yards beyond Wyatt's Incline there is a junction in the level, where a road branches off to Barnes' Incline, 270 yards distant; and 200 yards further along the level from this junction there is a Siding, known as the "Little Seam Siding;" and forty yards further the level becomes a descending plane, called Carter's Incline,

thirty-five yards in length. Near the top of this Incline a small road branches to the right, and at the bottom another to the left, and Parfitt's Level continues forward, inclining upwards for a short distance, then resuming the ordinary course, passing two stall roads on the left, and reaching the face in about eighty yards.

Returning to the top of Wyatt's Incline, a road is driven to the right into an air-way, termed "The Tunnel," and from this road an inclined plane, called Parnell's Incline, is driven up across the strata to the Great Seam, upon which a small district of workings is opened. A circuitous road, known as "The Tunnel," commences at the top of Peter's Incline, communicates with Wyatt's Incline by the road above named; and joins Parfitt's Level between the junction to Barnes' Incline and the Siding.

Returning to the communication, another junction occurs at Gullick's Incline, which is an ascending plane, and at its upper end a level road is driven to the bottom of Pitman's Incline, where a junction is made with the Slyving Seam workings off the North branch. Pitman's Incline rises up through the strata between the Slyving and Top Little Seams, and there are considerable workings beyond; but the last traces of the disaster in this direction, were within forty yards of the Incline.

Opposite the junction with Upper Conygre Downcast Shaft, a small district of workings is opened upon the Little Slyving Seam.

At the bottom of Upper Conygre Upcast Shaft, a road is driven across the strata, called the North Branch, which intersects the Slyving Seam, where a junction is formed for a small extent of workings opened there, and which join into the road coming down from the bottom of Pitman's Incline.

The North Branch is continued forward until it intersects the Top Little Seam, where another junction is formed, and workings developed. The last disruptive evidence of the disaster in this direction was found here, but the Branch is driven some distance further, and a Regulator Door beyond the junction was observed to be fully open, but there were no traces of explosive phenomena there.

The ventilation of the Collieries was largely increased about six months before the disaster, but the roads remained of the same sectional

areas; the air currents had therefore to travel at much higher velocities, which necessarily caused an augmented deposition of coal-dust from the loaded trams, and a larger evaporation of the moisture in the workings.

The air descending the Lower Conygre Downcast Shaft is divided, one portion entering the communication at the staple, Plate I.; and in ordinary circumstances this current measured from 8000 to 10,000 cubic feet per minute. It passes through the communication where the shot was fired direct to the top of Peter's Incline, where it is stopped by double doors, and diverted into the "Tunnel." The entire current goes through the "Tunnel;" a door at the bottom of Parnell's Incline bars its escape there into Wyatt's Incline, and it passes into Parfitt's Level inside of the junction to Barnes' Incline (on either side of which doors are fixed), so that the air goes direct to the end of the Level, being kept in its course by stoppings in side roads, and a door in the stall road at the foot of Carter's Incline. After ventilating the coal faces there, the current is made to circulate to the coal faces in Barnes' Incline, and to some other faces beyond, and is then diverted into the workings of Parnell's Incline. The current finally descends Parnell's and Wyatt's Inclines, enters the communication inside of the doors at Peter's Incline, and proceeds to the junction with Gullick's Incline, where it is reinforced by the return air from the workings beyond Pitman's Incline, which are ventilated by an independent current from Upper Conygre Downcast Shaft. The combined return air currents pass along the communication to the junction with the Little Slyving Seam workings, which they ventilate, and then direct to Upper Conygre Upcast Shaft.

A third current circulates from the Upper Conygre Downcast Shaft through an incline on the east side, and a portion of it returns back through the Regulator Door at the end of the North Branch, ventilating the Top Little Seam workings there, and on reaching the junction with Slyving Seam workings, it is joined by the return air of those workings (which is a split from the return air at Pitman's Incline), and enters Upper Conygre Upcast Shaft with the return current from the communication.

Coal was conveyed over the roads and inclines already described, the inclines being worked as self-acting planes; the ordinary conditions

therefore prevailed which are found to bring about a deposition of coal-dust upon the haulage roads.

The dust upon the floors of the roads and inclines varied considerably; in some places, and especially upon the inclines, it was mostly coal; in other parts it contained a large admixture of argillaceous matter.

The dust in Peter's and Wyatt's Inclines, and the workings beyond, was very dry. It was also dry in all the other inclines, and in the North Branch and the workings there. The communication from Lower Conygre Shaft to the foot of Peter's Incline was watered periodically; and at the latter point there was a little natural moisture. From the top of Peter's Incline to the Upper Conygre Upcast Shaft, there were patches and short lengths of damp ground at varying intervals, but, with these exceptions, the road was comparatively dry. In the roads and inclines traversed by the disaster, the roof and sides were free from the trickling water, or even drops, that are often yielded in the strata of mines: nor were there any pools of water upon the floor.

THE EXPLOSION.

THE Collieries are worked in three shifts of eight hours each, the last of the daily series commencing at 8 p.m., in which repairing work is done, and the roads and working places examined and certified, preparatory to resumption of the general operations of coal getting the following day. On the evening of February 6th nine men went into the Collieries to perform these duties. George Speering and John Keeling were to examine and certify the workings of Upper Conygre; and John Gage and George Flowers the corresponding duty at Lower Conygre Colliery. Flowers was accompanied by John Fear, and Gage took the district in which the remaining men were engaged. James Carter was ordered to fire a shot in the communication, and build up a side wall with the *débris*. James Durham, Joseph Bridges, and George Harding, were to do some repairs in Parfitt's Level and Carter's Incline. The only shot to be fired was the one in the communication entrusted to Carter, and there was not any other work to be done requiring the employment of explosives. Carter was the only man who had explosives in his possession.

These men descended the shafts at 8 p.m., Speering and Keeling at Upper Conygre, the remainder at Lower Conygre. Flowers and Fear were directed to their duties in the workings on the south side of the shafts; Gage was instructed by the Bailiff to examine the place where the shot was to be fired, and satisfy himself that it was in a proper condition, before Carter commenced his work; and having done this, he had a similar duty in Parfitt's Level and Carter's Incline, where Durham, Bridges, and Harding were to be engaged.

About 9 o'clock an explosion occurred, killing seven of these men. Flowers and Fear escaped unhurt; the explosion was not propagated into the district in which they were employed. They

did not hear any sound of the explosion, but they were alarmed by an unusual smell in the air current, and proceeded towards the place where they knew Carter was to fire the shot. They found that the communication was filled with "smoke," and after many ineffectual efforts to penetrate it, they retreated to Lower Conygre shaft, and signalled for assistance.

About the same time the engineman on duty at Upper Conygre shafts heard a noise which he compared with the fracture of a steam pipe, and an escape of steam; and on going to the Upcast shaft he found volumes of smoke and dust rushing up out of the workings. He informed the Under Manager, who, on finding that the entrance to the workings through Upper Conygre shaft was barred by the ascending smoke, and that the winding engine was itself damaged, proceeded with the Bailiff to Lower Conygre, and they were descending the shaft when Flowers signalled for help. They were joined by Mr. F. R. Foot, the agent and manager, and search was immediately made for the missing men.

The double doors between the Lower Conygre Downcast and Upcast shafts were undisturbed, as well as the Regulator door in the communication. The first indication of anything unusual was the displacement of an old wall stopping in the communication, and Carter's clothes, tools, and powder canister lying on the floor about 190 yards from the shaft. About forty yards further some *débris* was on the floor, which they observed was due to the shot that had been fired, and Carter's lifeless body was found seventy-seven yards beyond the shot, in a refuge hole at the bottom of Peter's Incline. About half way up Peter's Incline the arch had collapsed, blocking the road: but a way was made over the *débris*, and the top of the Incline reached, where progress was arrested by another fall. A passage way was again made over the *débris*, and a third fall found in Wyatt's Incline. These falls were of limited lengths, and the rescue party could travel through the intervals between them without any difficulty; and these conditions prevailed throughout the field of the disaster. The rescue party was, however, opposed by a more serious difficulty; the doors which controlled the currents of air were shattered into

fragments, the ventilation was suspended, and the workings filled with foul gases that produced unconsciousness. By means of brattice cloth, the intake air was forced into the poisonous gases, driving them towards Upper Conygre Upcast shaft ; and ultimately Durham was found in the siding in Parfitt's Level, Bridges and Harding in the south road near the top of Carter's Incline, Gage in the north road at the foot of that incline, Keeling in a corner of the junction in the communication with Upper Conygre Downcast shaft, and Speering a short distance away in the communication, nearer the Upcast shaft. Each one had succumbed to the immediate effects of the disaster, all were burnt, and one was mutilated.

The field of disaster presented the phenomena of numerous disturbances in falls of roof, shattered doors, and broken trams, at widely distant points ; but the spaces that intervened between these disruptions, betrayed no evidence of violent forces ; the timber, trams, and loose materials they contained were neither displaced nor damaged. These varied phenomena being the natural effects of the forces generated in the explosion, it is necessary to consider them in detail, in seeking to elucidate the causes by which they were produced.

It will be remembered that the separation and regulator doors at the Lower Conygre shafts were undisturbed, consequently they were outside of the explosive forces. The first evidence of disturbance was about 140 yards from these shafts, where a road had been driven on the Great Seam at right angles to the communication, and was abandoned many years ago, when the entrance was partly filled with *débris*, and a wall built up in front. This wall was found displaced into the communication.

About fifty yards beyond, Carter's clothes, tools, and powder canister were on the floor near to a tram, but neither the tram nor the materials were damaged. The shot was about forty yards further on, where the hole was found fractured from end to end, with the excavated *débris* lying underneath, and the timbering in its vicinity undisturbed. At fourteen yards inside the shot, there was another old road on the Great Seam, the side walls of which and the *débris* that filled the entrance, were also displaced into the communication ; and at twenty

yards beyond a similar old road, again, where under ordinary circumstances Carter would have sheltered himself from the shot; his bag containing his food was found here as he had placed it, hanging from the timber in the roof; it was blackened but had not been subjected to any violence, nor was the timbering disturbed. Four empty trams were in the siding near the food bag, and remained uninjured.

At the bottom of Peter's Incline there were more trams which had not been damaged, but some timber was displaced, and Carter's body was found with a small wound on his head; with this exception he had suffered no violence. The refuge hole in which Carter was sheltering himself, was on the right or west side of the communication, and his natural position of rest would be facing the east side, with Peter's Incline upon his right hand. The wound was on his right temple, and if caused by an explosive force, that force must have come down Peter's Incline. There was nothing to suggest that there had been an explosive ignition of gas here. Such an explosion must have wrecked all the timber, crumpled up the trams, and caused violent effects upon Carter's body, which could not have escaped the mutilation Keeling suffered, and that characterized many bodies at the centres of explosive violence in the Albion Colliery explosion.

About mid-way of Peter's Incline, five yards of arching which was in a very dry condition had collapsed. At the brow of the Incline about ten yards of arching had also fallen in with a considerable amount of *débris*. The landing stage here was of extra width and height, and beams of timber were fixed across from side to side over the travelling road, forming an overhead platform, upon which was erected a drum for working the Incline. This drum was built up of two cast-iron flanged wheels, 4 feet 6 inches in diameter, which were fixed upon the drum shaft four feet apart, and joined with distance pieces of wood, forming the barrel on which the rope coiled. Several empty trams were standing on the rails underneath the drum, and close by were the double ventilating doors. The overhead platform was found rent into pieces, one of the cast-iron wheels of the drum was broken up, and the whole displaced towards Upper Conygre. The double doors were shattered to fragments, and scattered along the communication in the

same direction. The trams were broken and crumpled up, the iron-work reduced to an octopus form, and one half of a tram wheel 12 inches diameter and 2-inch tread, was found a short distance away. The remains of one tram were upon the landing with the base frame left upon the wheels and axles, but the ends had been blown off in opposite directions; one portion had been projected outwards down the Incline, the other part was projected inwards to the double doors. This exhibition of explosive violence locates the first gaseous explosion upon the Lower Conygre side, at the top of Peter's Incline. The condition of the tram on the landing with its ends blown out in opposite directions, fixes the centre of that explosion, the forces of which were expended outwardly in wrecking the arch of the incline; and inwardly in shattering the stage, drum, trams, and doors, and hurling them in that direction. The explosive violence was exerted on the landing in a limited space, and rapidly died out on both sides. The tremors set up, and the immense changes of temperature in the communication between the shot and this explosion, afford an adequate explanation of the collapse of the arch in the mid-way of the Incline, and of the displacement of the timber at the bottom. On the inside of the double doors some timber had fallen, but there were no disruptive effects until about mid-way up Wyatt's Incline in one direction, and for some distance along the communication in the other.

The broken and crumpled condition of the trams at the top of Peter's Incline, is conclusive evidence that they had been in the immediate vicinity of a violent explosion. The uninjured condition of the trams at the foot of that incline, and in the siding between that point and the shot, afford equal proof that there had been no explosion in the communication where they were standing. Add the further evidences of Carter's freedom from mutilation, and the undisturbed condition of the timbering and food bag, and the proof is complete that there was no explosion in the communication, between the shot and the top of Peter's Incline. All the observed effects, therefore, demand for their explanation a local gaseous explosion in the top landing of that incline.

Pursuing this investigation first into the western district up Wyatt's Incline, the first thirty-three yards of that incline were not disturbed; but

from that point to the brow, the timber was displaced and the roof had fallen in. The top landing of the incline was of considerable size, and received the double traffic arriving from the Top Little Seam workings in Parfitt's Level, and the Great Seam workings of Parnell's Incline. The junction with Parnell's Incline formed a second landing, at the end of which the door was fixed, barring the entrance to the "Tunnel" air road. A tram loaded with coal was standing in this junction at the time of the disaster, and there were empty trams on the landing of Wyatt's Incline.

The empty trams were broken, crumpled, and driven to the inside end of the landing, and mingled with stones and *débris*. In the opposite direction there was timbering at the brow of the Incline which was driven downwards, knocking out the timber below, and causing a fall thirty yards in length. The loaded tram of coal in the junction weighing about 16 cwt., was propelled past Parnell's Incline through the door: and tram, coal and fragments of the door, were found in a shapeless mass, some yards beyond in the "Tunnel" air road. Immediately beyond the boundaries of these disruptive effects, the Incline, the Tunnel, and Parfitt's Level, betrayed no evidence of explosive violence. The disruptions were therefore local, and indicated force in three directions, inwardly into Parfitt's Level, outwardly down the Incline, and laterally into the "Tunnel" air road. The loaded tram of coal was standing at rest upon the rails in the junction, about eight yards from the door through which it was propelled as through a target. If this direction of force be extended backwards to the lines of force in Wyatt's Landing, their intersection determines the centre of the explosive forces, and locates a second local gaseous explosion. This explosion was separated by an interval in time and space from the explosion in Peter's landing, and for reference it will be called No. 2 Explosion.

No. 2 Explosion was propagated up Parnell's Incline, and into Parfitt's Level.

Parnell's Incline was not damaged for the first sixty yards from the junction, but at the top landing where roads were formed on both sides, explosive violence was developed, displacing the timber supporting the roof, which in falling knocked out other timber below, causing the

top part of the Incline to collapse for forty yards. This fall was not cleared when the Author made his inspections, so that the limited workings emanating from the Incline could not be examined.

It is impossible to conceive that the disruptive forces in No. 2 Explosion could have exerted these violent effects at the top of Parnell's Incline 100 yards distant. The only force available in this direction was the one that propelled the tram through the door; and to suppose that it was exerted up Parnell's Incline, is to imagine that it turned through a right angle, passed up an ascending plane 100 yards without disturbing the timbering, and then exerted violent energy back down the Incline it had traversed. This could not be true of a force generated by the explosive ignition of a gaseous body, which rapidly diminishes in power as it moves from its origin. The disruptive violence effected at the top of Parnell's Incline, can therefore be only reasonably attributed to a third gaseous body, produced and oxidized by a repetition of the processes by which Nos. 1 and 2 Explosions were brought about, and numbering No. 3 Explosion. The coal faces were within a short distance of the *locus* of No. 3 Explosion, and in the circumstances that prevailed, there can be little doubt that propagation ceased in this direction, at the top of the Incline.

Returning to No. 2 Explosion and its second branch of propagation into Parfitt's Level, it should be observed that this level enters a large extent of workings on the Top Little Seam, which generally has a compact stone roof, and requires a limited quantity of timber for its support, except where the strata is faulty, or shales intervene between the coal and the stone, conditions that are sometimes found. The roads on this seam where the roof is strong, admit of no more disintegration by the forces of a gaseous explosion, than the bore of a cannon when the charge is fired; consequently there were no falls of any importance in these workings. For considerable distances, the unbroken and undisturbed condition of the timber and rails showed that there had been no explosive violence there; but at some places doors were shattered, trams broken, and rails displaced, affording demonstrative evidence that there had been explosive violence in their vicinity.

The first disturbance in Parfitt's Level was about seventy-five yards

from Wyatt's landing, where a junction was formed by a road coming in from Barnes' Level and Incline. There were two doors here, one on either side of the junction, to control the air currents. Between No. 2 Explosion and the first door there were no evidences of disruptive force, but both the doors were shattered into fragments and scattered into the Level beyond, and their iron hinges were either bent into arcs of circles, or broken through the bolt-holes. These doors had adequate bearing surface against their frames, and were sufficiently strong to resist any conceivable rush of air. Their destruction into small pieces of two or three square inches of superficial area, the rupture of the door posts through the hook holes, and the fracture and bending of the iron-work, must have been brought about by an immediately adjacent explosion; and these effects could only have been produced by the repetition of the conditions in which similar doors at the top of Peter's Incline were broken up in like manner, making No. 4 Explosion.

This explosion propagated in two directions—one into Parfitt's Level, the other through the road to Barnes' Incline. About 220 yards beyond the doors, Parfitt's Level becomes a descending plane, called Carter's Incline, and shortly before this point is reached, there is a siding termed the Little Seam Siding, in which there were five trams. The outside four were loaded with *débris* and standing upon the rails uninjured, and their contents undisturbed; the fifth was empty, lying across the rails against the fourth, on the inside end of the siding, in a broken and crumpled condition. This crumpled tram could not have received its damage in the siding, as the loaded trams had not been subjected to any violence. Durham was also found in the siding, and he had not suffered any bodily injuries. A short distance down Carter's Incline, another empty tram was lying against the side wall, bulged out of shape, in a form that showed it had been violently projected there from above. These two trams, which were originally standing on the rails between Carter's Incline and the siding, had evidently been exposed to explosive violence, which must have been exerted between them, causing the damage they exhibited, and hurling them in opposite directions into the positions in which they were found, thirty yards apart. At an intermediate point near the brow of the Incline, the old road to

the right inclines downwards, and the timber props fixed at the corners were coated with coked coal-dust on their faces towards the brow, showing the force that produced the deposition was from the outside. The clothes and candlesticks belonging to Bridges and Harding were found in the same place, and down the old road Bridges was lying upon his chest, head foremost, in a position that showed he had been driven with some force, the head being against the side of the road, and the face twisted round over the shoulder. Evidently he had been rendered insensible and had died at the place to which he was projected. Harding's body was found two or three yards further away, in a reclining position, and evidently he was the first in trying to escape. There was no mutilation or dismemberment of the bodies, therefore they had not been exposed to the direct violent energies that crumpled the trams; but their clothes were partly ripped open and torn away, showing that the explosive forces had reached them when the energy was diminished, but still possessing adequate power to propel their bodies in the direction in which they turned to escape. Between this old road and the siding, there was an enlarged space in which the drum for the rope of Carter's Incline was fixed overhead, and neither the drum nor its platform were disturbed; some props of timber only had fallen from under the roof. The only objects upon which the explosive forces could be visibly exerted, were the drum and platform, the trams, and some isolated props of timber, or the bodies of the two men; it is not difficult, therefore, upon the evidences, to fix this No. 5 Explosion between the drum and the brow of the Incline; and to observe the limits of its direct violence in opposite directions, at the crumpled trams on either side: and of its indirect force upon the bodies in the old road.

At the bottom of Carter's Incline, about forty-five yards from No. 5 Explosion, there was a junction with a stall road to the left, and a door stood at its entrance, to divert the air current into the end of Parfitt's Level. This door was shattered to pieces and distributed along the stall road, and Gage was found beyond the remains of the door frame, slightly burnt, and wounded in his head only, probably by fragments of the door striking him. There was no other

disruption here—the roof was strong, and there was an absence of materials that could be broken or displaced. The nearest evidence of No. 5 Explosion, was the tram that lay up the inclined plane thirty yards distant. The forces that broke the door into particles must, therefore, have been generated in an immediately adjacent explosion, as at the preceding doors, making No. 6 explosive ignition. The door was the only object here that could afford evidence of the direction of the explosive forces, but the ignition of a gaseous body in the junction, necessarily involved the expenditure of the forces into all the passages at that point.

Parfitt's Level continues about eighty yards beyond No. 6 Explosion, and two stall roads branch off at intermediate points to the left, the last one at about ten yards from the face. There were no disruptive effects in these workings; the roof of the level was friable and needed a full complement of timbering, but timber and roof were alike undisturbed. A tram loaded with coal was standing upon the rails of the junction of the last stall, undamaged and its coal unmoved, in direct contrast with the condition of the loaded tram at Parnell's Landing, in No. 2 Explosion. The exposed faces of the blocks of coal on all sides of this tram, had been subjected to intense heat, which had distilled out volatile matters; and on the ledges of the coal, and the edges and buffers of the tram, there were accumulations of globules of coke. In Parfitt's Level, about seven yards outside of the loaded tram, there were five successive sets of timber more or less covered on their inside faces with thick masses of coked coal-dust.

The termination of the disaster in this direction has now been reached, and it has been shown that No. 6 Explosion failed to propagate itself into the workings beyond, though there was an extent of road exceeding what had proved adequate for the processes that produced the preceding explosion, and the condition of large sectional area that had characterized their *loci*.

The thick deposits of coked dust upon the timber, show that there was adequate coal undergoing distillation to yield an explosive gaseous body: and the globules of coke on the loaded tram, indicate that tram

and coal were enveloped in gases at an exalted temperature, certainly higher than the temperature required to determine their ignition: but there was no explosion there. The disaster terminated in the presence of the source of explosive gases, and of heat for their generation and ignition; it is therefore obvious that another condition, that is essential to complete the cycle of activities closing in a gaseous explosion, was absent at the last junction in Parfitt's Level, and wanting this element an explosion could not be brought about, so that the process languished to extinction. This absent element must be considered in a subsequent chapter.

Returning to No. 4 Explosion at the doors, the second branch of propagation effected violent energy at Barnes' Incline, 270 yards distant. An empty tram had been left standing on the top landing there, and after the explosion the body was found collapsed diagonally about seven yards down the Incline. One axle was broken off inside the wheel, and found with the other axle and its wheels at the bottom of the Incline. This tram had been subjected to an amount of violence not easily realized, and manifestly locates No. 7 Explosion about 266 yards from No. 4 Explosion in Parfitt's Level. A door in the intermediate road which opened towards Barnes' Incline was thrown open, and coked coal-dust was found further on (see Plate I.).

The coal faces in Barnes' Road were eighty yards distant from Barnes' Incline, and other faces were about two hundred and fifty yards away: but they had suffered no disturbance, nor was there any evidence of propagation from No. 7 Explosion. The roads were dry and dusty, the heat generated in No. 7 Explosion was available, and if these conditions were sufficient, there was no reason why the explosion was not propagated down Barnes' Road, and to the other distant coal faces. As a fact, the disaster terminated at the top of Barnes' Incline, and manifestly a necessary element was also absent here, as the chemical actions ceased.

The disaster has now been traced in its ramifications into the workings through Wyatt's Incline, and the consideration of its propagation from Peter's Incline along the communication, may be resumed.

From Peter's Incline to Upper Conygre shafts, the communication

passes through considerable lengths of friable and faulty strata that gutter upwards, forming hollow spaces in the roof; and the road is kept open by timber or arches. Where timber is fixed, the hollow spaces or cavities are more or less open over the bearers. About one hundred and twenty yards from Peter's Incline, there was a fall ten yards in length, and fifty yards beyond another fall eight yards long. Between these falls and at their outside ends, there was an amount of crumbling and scaling of the roof and sides, but it was evident that this disintegration did not indicate an explosion of a gaseous body, co-extensive with the extreme displacement of timber and arches, but rather a limited and violent force that set up tremors in this strata: which, with the immense changes of temperature, brought about this protracted disturbance. In these circumstances, timber would be unkeyed and dislocated, the arches would be lifted and shaken, and the observed effects must have followed as a natural consequence.

This phenomenon of disruption exhibited in the greater or less collapse of the communication for a distance approaching seventy yards, while the preceding one hundred and twenty yards outwards to Peter's Incline, and a greater distance inwards towards Upper Conygre, betrayed no such evidence of violence: shows that an explosion occurred to produce that disturbance, probably not far removed from the first fall, making No. 8 Explosion.

The next disturbance was about one hundred and seventy yards beyond, and here six yards of timber had fallen, which needed no explosive violence for its displacement, as there was a cavity in the roof over the bearers. The gaseous body at an exalted temperature which is now known to issue from each explosive ignition, must naturally play upon the walls of the road, especially where the timber props and bearers stand out round three sides of the square: it would also ascend into the cavity over the bearers, and being followed immediately by cold gases, disintegrating effects in this cross jointed and friable strata, must have followed. In these circumstances, it can be readily understood that the upper ends of the props, which were held in position by pressure against the strata, would be unkeyed:

and the bearers having no support against the roof, but resting on the props, would collapse with them.

The junction with Gullick's Incline is about forty yards further on, and explosive violence was exerted here: the timber and roof in the junction were broken down, rails were displaced, and an empty tram standing on the rails to the Incline, was hurled across the junction into the communication. The tram measured 5 feet long, 2 feet 9 inches broad, 2 feet 6 inches above the rails, and weighed about 5 cwt.; and its lateral displacement across two lines of rails demanded violent energy. The tram rested in the communication, though the explosion was propagated a considerable distance beyond, which shows that the force that displaced it was local, and quickly expended; as had that force been continuous through the communication, it must have carried the tram for some distance towards the Upcast Shaft. The original position of the tram, therefore, fixes the centre of an explosive ignition in the Junction, the violent energy of which was expended in breaking down the timber and strata, displacing the fixed rails, and hurling the tram away: making in numerical order No. 9 Explosion.

This explosion was propagated in two directions, one branch going up Gullick's Incline, the other through the communication to Upper Conygre shafts. Gullick's Incline with its fifty yards of close timbering was undisturbed, but its top landing was wrecked and filled with a confused heap of timber and *débris*, while the road beyond to Pitman's Incline, for a distance of about ninety yards, was undamaged and its timber unmoved. This exhibition of violence in Gullick's top landing, centrally between the thickly timbered and undisturbed incline on one side, and the undamaged road and unmoved timber on the other, locates No. 10 Explosion.

The next disturbance was found in the Junction at the foot of Pitman's Incline, where an air road joins in from the Slyving Seam workings of the North Branch. A door was fixed in the air road several yards from the junction, to regulate the air current, and after the disaster it was observed to have been broken up, and the fragments scattered towards the Slyving Seam workings. The

Junction, which also contained the bottom landing of Pitman's Incline, presented a scene of destruction, and was filled with a mixed mass of *débris* and timber; but this wreckage ceased a short distance above the landing, and the Incline itself was then found open and undamaged. This disturbance is also found to be of an isolated character, the road that preceded it, and the incline that immediately followed, present the contrast of an undisturbed condition. The fall, and the fragments of the broken door, determine the centre of this violent energy to have been in the Junction opposite the air road, and fix the *locus* of No. 11 Explosion.

Pitman's Incline is an ascending plane about seventy yards long, in dry and friable strata, timbered at both ends and arched in the middle. Five trams were standing on the rails in the top landing, loaded with coal before the disaster, but were subsequently found in a disordered state, with their contents scattered all over the place. Four empty trams were also resting here, two of which were crumpled up, but the adjoining two were not much damaged. The timber in the landing, and at the top of the Incline was broken down, and the place presented a ruin of coal, *débris*, timber and trams. The middle portion of the Incline it will be remembered was not injured, and at the upper end a timber prop stood on the left hand side covered with coked coal-dust on its upper face only, showing deposition by a force from above. In the opposite direction from the landing inwards, the road was undisturbed for some distance; therefore the destruction in the landing itself affords another exhibition of local explosive violence; and its rapid expenditure is seen in the fact that while the first two empty trams were crumpled, the adjoining two were practically undamaged. This disturbance makes No. 12 Explosion.

At the end of Pitman's Landing, the road was arched for about thirty yards, and then the timbering recommenced. The first few frames of this timbering were found displaced, and an examination of the place showed that this displacement was an effect of No. 12 explosion, and it formed the last evidence of disturbance in this direction.

The working faces were about five hundred yards beyond this fall, and loaded trams of coal were daily conveyed along the road,

so that coal-dust was present, and in a dry condition. The explosive phenomena however, terminated at the fall, and the discussion of this failure in propagation must be delayed for another chapter, as evidences have been already advanced showing that other elements besides coal-dust, are demanded in the propagation of explosions.

Returning to No. 9 explosion at the Junction with Gullick's Incline, and following its second propagation along the communication, the first thing to attract attention was some fallen timber which had been unkeyed in the way already explained; and at the stables one hundred and twenty-five yards distant, four horses were found burnt, but not mutilated; and there were no disruptive effects there.

About sixty-six yards beyond the stables, there was an outburst of violence in the Junction, where one road joins in from Upper Conygre Downcast Shaft, and another from the workings on the Little Slyving Seam. Doors were fixed in the communication to divert the air into these workings, and in the entrance of the road to the Downcast Shaft. These doors were reduced to bits, and distributed one towards the Downcast, the other towards the Upcast Shaft, and a masonry wall in the angle between them was wrecked. The air in the Downcast would now escape direct to the Upcast Shaft, and cut off the supply to the workings beyond Pitman's Incline and the North Branch. The timber in the Junction, and the road to the Little Slyving Seam workings, was broken down. The remains of Keeling were found in the entrance of the road to the Downcast Shaft burnt and mutilated; and Speering's body was in the communication beyond the door frame, burnt but not mutilated. All the disruptive effects were within a small area, indicating a local explosion, which the shattered doors, mutilated body, and displaced timber, fix in the Junction, about one hundred and ninety yards from the preceding explosion in the communication. These evidences constitute No. 13 Explosion.

The Upper Conygre Upcast Shaft, which was within forty yards of the last named Junction, was the scene of a very violent disturbance. There were trams in the shaft siding, and in the junction with the North Branch; some were blown bodily into the shaft sump, others

were broken and crumpled, and timber and materials in the immediate vicinity were displaced with violence. The cage which was suspended in the shaft between wood guides a few feet above the communication, was propelled up the vertical shaft for at least sixty feet (as twice that length of flat wire rope by which it was attached to the winding engine at the surface, was kinked and split open), and fell back breaking one of the D links of the bridle chains. The wire rope, which had a tensional strength of thirty-three tons, was not fractured, so that the energy due to the weight and the velocity of the fallen cage at the moment of its arrest by the limited length of rope, was transmitted to the drum shaft of the winding engine, and the fly-wheel shaft being tightly held by its brake, the toothed wheels by which these shafts were geared to each other were partly stripped. The teeth were 1½ inch thick at the root, and 8 inches wide; three were broken off the spur, and one off the cog-wheel. This disturbance, making No. 14 Explosion, was also limited in character: at short distances from the siding, both in the communication and in the North Branch, the disruptive effects ceased, and the normal condition of the roads prevailed.

Although a large portion of the heat at this explosive centre must have escaped up the shaft, a quantity adequate to renew the chemical actions in the coal-dust, passed into the North Branch, and propagation was continued in that direction.

The North Branch commences in the shaft siding at a large angle, and was in an undisturbed condition up to the junction with the Slyving Seam one hundred yards distant; but there the roof and timber were broken down, beams of timber were fractured, and the faces of the arches at each end of the Junction were shattered. Eight yards of the Junction, and several yards of the Slyving Seam road, were filled with broken timber and *débris*; but these distances marked the limits of destruction; the Branch, for about one hundred yards on one side and fifty on the other, and the Slyving Seam road, for about forty yards from the Junction, were in their normal condition. This solitary exhibition of violence, in which one beam of timber nearly a foot square, fixed vertically under the roof, was snapped off in two, and the masonry at the ends of the arches shattered, makes No. 15 Explosion.

This explosion was propagated, both into the Slyving Seam workings, and further into the North Branch. About sixty-five yards from the Junction, the Slyving Seam road branched in two directions (Plate I.), the right hand road communicating with the air road from the foot of Pitman's Incline, the other diverging to the left and ending in two stall roads. Doors were fixed in these right and left roads, the former about ten yards, the latter about twenty yards from their origin, and both doors opened towards the faces; the former was found broken to pieces, the latter was simply split open. Immediately outside of these roads, and towards the North Branch, eight yards of timbered roof was broken down. These effects locate the limits of the disruption; the roads outwards to the junction on one side, and inwards from the doors to the coal faces on the other, were undamaged, and their timber not moved. The disturbance was not marked by the amount of violence observed in other places, but it was isolated, and forms No. 16 Explosion.

The coal faces were distant about forty-five yards from the right hand door, and sixty, and one hundred and thirty yards respectively from the left hand door, but they betrayed no indications of explosive phenomena, except where the air road from Pitman's Incline joined in. The heated gases from the explosion at the foot of Pitman's Incline had reached this point, and the props were set free by thermal effects on the roof. No. 16 Explosion, therefore, did not effect propagation into the coal faces, although the conditions of coal-dust and dryness prevailed.

Returning to No. 15 Explosion at the Junction, and proceeding some distance in the North Branch, there was no disturbance calling for notice until a point was reached where the strata was cut up by cross jointing, and the roof had guttered upwards forming an open cavity over the timber, for a distance of thirty yards. All this timber was displaced and mixed up with fallen *débris* from the roof and sides. This disturbance appeared at first to be the result of thermal effects already explained: but the extent of the fall demanded more force for its explanation, and at one point the rails, which were secured to wood sleepers on the floor of the road, had been forced from their positions.

The fallen timber and *débris* may have displaced the rails and sleepers bodily, or sprung a rail from its fastenings: but these rails were wrenched wholly from the sleepers, and thrown to the sides of the road. These phenomena of the rails, and the quantity of timber and *débris* thrown down, could only have been produced by disruptive force. This force was evidently developed in the vicinity of the displaced rails, and expended in the fifteen yards upon either side: as the Branch, exterior to this disturbance, for many yards inwards and outwards, had suffered no violence; and makes No. 17 Explosion.

There were no explosive phenomena in the Branch for a long distance beyond No. 17 Explosion, until the Junction with the Top Little Seam was reached, where a door that opened inwards was broken into particles, and formed the solitary evidence of disruptive force. The roof here was very strong, and required no timber support: and there were no loose materials upon which the explosive energy could have been visibly expended. The door would have readily opened to a puff of the gaseous body that issued from the last explosion, but its shattered condition with the fragments spread along the Branch inwards, demanded for its explanation an immediately adjacent explosion, which numbers No. 18. The Top Little Seam workings here, were reached by an inclined plane from the Junction, which was very dry and dusty; and the same condition prevailed in the North Branch beyond the broken door; but the propagation of No. 18 Explosion entirely failed either up the plane, or along the Branch.

Several hundred yards beyond this explosion there was a Regulator Door fixed in the North Branch, and it was found open after the disaster; there was no disturbance of any kind between the No. 18 explosion and the Regulator, and the fact of it being found open, will occasion no surprise when it is remembered that the ventilating currents were disturbed and broken up, by the destruction of the main doors, and the separation door between Upper Conygre Downcast and Upcast Shafts.

The developments of the disaster in the workings of the Collieries have now been traced, and a further examination of the phenomena at the Upcast Shaft after No. 14 Explosion, will assist in forming an idea

of the immense volumes of gas that must have been produced and oxidized in the numerous explosions, and their antecedent chemical actions.

The coal was raised through this shaft, but the winding engine being geared to effect a slow motion; and the trams sheltered in a cage with shallow decks, they could lose no appreciable quantity of coal in their ascent. The walls of the shaft could not in these circumstances have held any sensible deposition of coal-dust in a condition to contribute to the phenomena of the explosions. The volume of effluent gases that issued from the shaft, must in the first instance have been the products of the explosions in the vicinity. The night was dry and exceedingly cold, and the engineman on duty was attracted to the shaft by a noise which he thought was due to the bursting of a steam pipe, and the escape of steam (contemplating the low pressure used for the condensing winding engine). The noise he heard was no doubt the jerk of the falling cage upon his engine, breaking the teeth of the toothed wheels, representing forty-eight square inches of cast iron, and causing the drum shaft to revolve. At the shaft, however, he saw volumes of smoke and dust issuing and rising above the pit head gear, but effecting no damage to the structure. Three hours after the disaster these effluent gases were still inimical to life, though the separation door between Upper Conygre Downcast and Upcast shafts was broken, and the downcast air was mingling with the products of the explosions. Meanwhile the fresh air of Lower Conygre Downcast Shaft was being forced into the foul gases in the workings, driving them towards Upper Conygre; but for over seven hours, the poisonous gases were flowing out of the Upcast Shaft there, and some further period was occupied in eliminating the products of the explosions from the mine. An idea of the quantity of these products may be gained in the fact that, at the small velocity of ten feet per second, over 700,000 cubic feet of gases, in which no life could exist, issued each hour from the Upcast Shaft.

Some conception can now be formed of the magnitude of the distillatory action in the coal-dust distributed through the workings, and the large aggregate quantity of explosive gases that must have been generated, and in part oxidized, to have produced the immense volume of vitiated air and gases that issued from the Upcast Shaft.

The following tabular statement of the explosions that have been traced, and the distances between their suggested centres of ignition, will convey some idea of the extent of workings in which distillatory action occurred :—

						Yards
From	No. 1	Explosion to	No. 2	Explosion,	against the air current	123
,,	No. 2	,,	No. 3	,,	,, ,,	117
,,	No. 2	,,	No. 4	,,	diffusion alone exerting a current	66
,,	No. 4	,,	No. 5	,,	with the air current	230
,,	No. 5	,,	No. 6	,,	,, ,,	45
,,	No. 4	,,	No. 7	,,	diffusion alone exerting a current	266
,,	No. 1	,,	No. 8	,,	with the air current	165
,,	No. 8	,,	No. 9	,,	,, ,,	263
,,	No. 9	,,	No. 10	,,	against the ,,	61
,,	No. 10	,,	No. 11	,,	,, ,,	88
,,	No. 11	,,	No. 12	,,	,, ,,	70
,,	No. 9	,,	No. 13	,,	with the ,,	187
,,	No. 13	,,	No. 14	,,	,, ,,	38
,,	No. 14	,,	No. 15	,,	against the ,,	100
,,	No. 15	,,	No. 16	,,	,, ,,	62
,,	No. 15	,,	No. 17	,,	,, ,,	77
,,	No. 17	,,	No. 18	,,	,, ,,	170
					Total	2128

The length of road preceding No. 1 Explosion, in which distillation was observed to have taken place, and also the spaces at some of the terminations, must be added to the foregoing :—

			Yards
From the Shot	to No. 1	Explosion - - -	191
,, No. 6	Explosion	to the tram of coal - -	77
,, No. 11	,,	to Slyving Seam face -	163
,, No. 12	,,	to Fall - - -	35
,, No. 13	,,	into Little Slyving Seam -	20
			486

These aggregate distances of 2614 yards indicate the extensive field of distillatory action, and the source of the immense volumes of gas that were produced.

Another branch of evidence is the depositions of coked coal-dust on the timber, trams, and floor of the workings, showing that the coal of which they were the solid residues, had been subjected to heat, and had yielded up its gaseous constituents to the atmosphere of the mine; and are direct evidence that gases were distilled from the coal. These coked residues are only visibly deposited under special conditions, and not in the general progress of the distillation. An obstruction in its progress, if presenting a surface to which the intumescent coal can adhere, will retain a deposit. An interference like a local explosion may project the coal in this hot pasty condition upon any surface opposing the lines of its forces. Where the distilling action is arrested, the gaseous bodies at these points may retreat, by virtue of the attenuated condition of the atmosphere behind, and impelled by air of normal tension in front, carrying with them coal in process of distillation, and deposit this coal upon surfaces favourable for its reception. The circumstances under which visible deposits of coke are effected, therefore disallow such depositions upon any scale comparable with the magnitude or extent of the distillatory action. If the floors of the roads could be examined immediately after a disaster, and before the fine dust set up by the violent movements in the air had subsided, coked residues would be found to prevail generally upon the floor.

The coke deposits were, however, found at many points. The first were on the lower ledges of the right wall of the communication, eighteen feet inside of the shot. This was observed by the Author thirteen days after the disaster, and was confirmed three weeks later, when the coke was still there. The next evidence was on the faces of the stones in the wall, between the foot of Peter's Incline and the Refuge Hole in which Carter's body was found. The lower face of this wall presented the appearance of having been at some time covered with a paint-like skin of material, resembling a mixture of dark oil and clay; and fine particles of coke were adhering to this surface. There were patches of coked coal adhering to the front end and the buffers of an empty tram in Wyatt's

Landing to a height of two feet above the rails, but the remaining six inches of wood to the top of the tram was clean. The landing was over six feet high, but no other deposition of coked dust could be found there.

It will be remembered that there were four loaded trams in the Little Seam Siding in Parfitt's Level; coked coal was distributed over the front end of the first one in the following manner:—The buffers, which were twelve inches above the floor, were hidden by coverings of coke three-eighths-of-an-inch in thickness, and the wood end of the tram was partly covered with patches of coke, which gradually thinned off to nothing at twenty-one inches above the floor; the upper nine inches to the top of the wood being clean. There was no trace of coked dust upon the flat iron angle pieces at the corners of the tram, the end of the draw bar and link, or the wheels and axles, with all of which the intumesced coal-dust must have collided: nor upon the remaining three sides of this tram. The other three trams were perfectly free from coked dust, and no other indication of it appeared in the siding.

A short distance beyond the siding, the staging was fixed that supported the drum for working Carter's Incline, and on the flat surface of the outside plank, the inside edge of which was coterminous with the under side of one of the beams, and four feet above the floor, there were long flakes of coked coal; but the adjacent face of the beam had no coked dust upon it, and there was no other observable deposit at the place. These coked residues were loose upon the plank, and could be taken off without breaking. They had not been carried there, like the intumescent coal-dust was forced against the ends of the trams, in a condition that caused it to adhere to vertical surfaces.

The next coked dust was upon the timber props at the entrance of the old side road in which Bridges and Harding were found. One prop was on the outside corner of the road, and two on the inside, practically in line with the side of Carter's Incline, with this qualification—one of the two inside props was fixed a few inches laterally away into the old road. The prop on the outside corner was coated with coked coal on its outer face only, for eighteen inches above the floor. The prop on the inside corner, and nearest to the Incline, was similarly coated on its outside face only, from the floor to within a few inches of the roof; but

the immediately adjacent prop had coked coal on its side next to this adjoining timber, and facing the Incline: and the outside face was clean: showing a sharp division between the atmosphere in which the intumescent coal-dust was suspended, and the air in the old road. This sharply divided line in the atmosphere, shows the immense velocity with which the hot pasty coal was projected against the props, which could only have been produced by the gaseous explosion, which has already been shown to have occurred between the top of Carter's Incline and this side road. The coke upon the tram of coal in the entrance of the last stall of Parfitt's Level, has already been referred to, also the coke deposits upon the timber outside; but the latter need further description. Coming from the stall outwards along the level, the first timber was a prop on the right hand side, and that was clean. The first frame of timber stood next, about seven yards outside of the tram, and the left-hand post was covered from floor to roof with a mass of coked dust, which also extended along the bearer next to the roof, but thinned off to the right side: but the right-hand post had a small deposit upon its lower end only; the next frame was heavily covered on both posts and bearer alike; the third frame was in the same condition; the fourth frame was likewise covered, but not so heavily; the fifth frame had a lighter deposit still; and the sixth frame had none. These deposits were exclusively on the inside faces of the timber.

Upon a dismantled door, in the corner of an angle in the road between Parfitt's Level and Barnes' Incline, there was a small quantity of coked dust near the floor (Plate I.).

The timber post in Pitman's Incline, with coked dust upon its inside face, has been referred to.

The importance of these observed deposits of coked dust, is their distribution over the field of the disaster, showing that at such widely distant points as the shot in the communication, the trams in Wyatt's Landing, and at the end of Parfitt's Level, and the timber in Pitman's Incline, the coal-dust was undergoing the same process of gas distillation. These distillatory actions necessarily had their inception at the origin of the disaster; their continuity in these propagations is demonstrated by the observed coked residues: and their prevalence in all the other roads

traversed by the disaster, is indicated by the identical modes of action they exhibited.

There were other evidences in deposits of carbon, which, though much less conspicuous than the coked residues, are of no less importance as a phenomenon in the disaster. This carbon was in a state of fine division, and in appearance resembled soot, though sometimes forming the striated and gossamer-like filaments that are occasionally seen in the coke from gas retorts, which, however, when collected, break down into fine powder. Copious deposits of this carbon, covered the timber and side walls of the roads and inclines, throughout the field of the disaster. Whatever question may be raised as to the extent of the visible coked residues, there can be no doubt that the carbon deposits were co-extensive with the explosive phenomena. Collections of the deposits presented no difference in colour in sunlight, though they appeared to vary from brownish-black to black in the workings, and there was no visible distinction between them and the deposits of carbon obtained from an ordinary gas flame. The Author pointed out the significance of the character and universality of these deposits in his former work,[1] and advanced the hypothesis that they were the carbon constituent of gaseous hydrocarbons, the deposition of which had been brought about by the oxidation of the hydrogen constituent. That hypothesis has its foundation in chemical science, and its exemplification in industrial chemistry; and its application by the Author in his elucidation of the rationale of the Camerton Colliery explosion in the early part of 1894, has not yet been contested.

Whatever the processes were, of which these deposits of carbon formed the solid product, there can be no question that the carbon had its origin in the coal-dust. The existence of this carbon is therefore demonstration that distillation of coal-dust was active co-extensively with its deposition, and therefore throughout the field of the disaster. The relation between the immense volumes of gases that were produced, and the field of their origin, will now be recognized.

The character of gases being known by the products of their oxidation, it is important to record here what is known of the atmosphere

[1] "Coal-Dust an Explosive Agent," pp. 54–55.

of the workings after the explosions. When the rescue party reached Peter's Incline, they found it blocked by falls, and the workings filled with stagnant and poisonous gases, thickly charged with down-like matter, in suspension. Two of the party described the state of the atmosphere in Parfitt's Level beyond Wyatt's Landing, as comparing with the condition that would be produced "By turning a bed tick inside out and shaking its down into the air."

Another feature of these stagnant gases was that they supported combustion, but were inimical to life. Everywhere the naked candles with which the rescue party worked, burned brightly; and the only indications they had of the presence of poisonous gases, were the physiological sensations they suffered, in the smarting of eyes and nose, with giddiness and loss of power, compelling them to retreat frequently, into the fresh air.

A further phenomenon was the condensation of water vapour yielded in the oxidation of the gas. It will be remembered that No. 3 Explosion caused a fall at the top of Parnell's Incline, which barred access to the workings, and shut in the gaseous products of that explosion and of any subsequent chemical actions. The roof at the bottom landing of the Incline was a large even surface of stone, which was cooled by the air passing through Wyatt's Landing, and probably by some leakage of air from the main in-take current in the "Tunnel," the escape of which was barred by the door only. The Author observed in his first inspection that these gaseous products which were of a pungent smell, were diffusing down the Incline to the air current: and in subsequent examinations found that they had partly condensed on the stone roof, which for an area of sixteen square yards was thickly studded with heavy drops of water, that were on the point of falling, insomuch that, on touching the roof with his finger, a small area was tapped, and the water instantly ran down his arm. This large condensation of water vapour from the gaseous products of an explosion, will prove to be as important as it is interesting in seeking a solution of the rationale of the explosions. It would no doubt have been repeated in all the explosive centres, had equally favourable conditions prevailed; and it was stated that this phenomenon had been observed in other parts of the field of the disaster.

The phenomena of the disaster have now been described, with the nature, extent, and terminations of the explosions; the source of the gaseous mixtures has been discovered, and some properties of the products of the chemical actions and gaseous explosions recorded; and their further consideration must form the subject of a future chapter, after the origin of the disaster has been localized, and its initiation elucidated.

THE ORIGIN AND INITIATION OF THE DISASTER.

THE ordinary method pursued in seeking to discover the origin of an explosion, has been to mark the directions in which forces were exerted, and trace them to their inception. It is founded upon the hypothesis that an explosion is a continuous "Blast," rushing through the mine: and upon that supposition the evidence of the directions in which forces were exerted has been complex wherever they have been observed. Many of the reports upon explosions in gaseous mines record this phenomenon with the expression, "Conflicting evidence of force," and if the hypothesis be introduced for the elucidation of the Timsbury Colliery disaster, equal difficulties arise.

The displaced positions in which materials were found in each disturbance in the Timsbury Colliery, demanded for their explanation forces moving in opposite directions from a common centre, and were antagonistic to the hypothesis of a continuous blast. Each disturbance was local and self-contained, and the spaces between them betrayed no evidence of disruption. In those conditions of local explosions, in which the forces necessarily radiate from the centre in all directions equally, it is impossible to discover the origin of a disaster from the directions in which explosive forces were exerted, and it would be travelling in a circle to pursue the inquiry in that direction.

The field of the disaster presents the phenomenon of numerous branches of propagation, the terminations of which disclose the end of the explosive activities in those directions, and determine their origin to have been at an antecedent centre. The cessations of explosive phenomena or failures in propagation, therefore, form well-defined points at which to commence the inquiry into the origin of the disaster. The preliminary question to be considered is whether the disaster had its origin in any one of the local explosions, that were found at various

points in the field of disturbance; and inquiry must therefore be made to ascertain what men were engaged, and what operations were in progress, at the *loci* of these explosions.

At the centre of No. 5 Explosion, the iron plates of the junction had to be raised and re-set: but with that exception there was no work to be done, or men to be engaged, at or near the *locus* of any of the explosions. Bridges and Harding were appointed to the work of re-setting the iron plates, but they had not commenced it when the disaster happened, nor had they left the resting place about forty yards distant, where they had taken their coats off preliminary to the operation, and where their bodies were found. The only man who was near the centre of an explosion was Keeling, and he was simply passing through on his way to the stables. It is therefore manifest that there was no operation in progress nor man engaged, at the points to which the numerous explosions have been traced: consequently there was no originating cause at the *locus* of any one of the disruptions, to bring about the initial explosion, and they must have been produced by an extraneous and antecedent cause. The disaster necessarily therefore had its origin outside the contour of these explosions. Commencing with the terminations of the explosive phenomena, they have now to be traced back through the field of disturbance, to discover the avenue through which the chemical energies entered, and to follow them to their inception.

It will be remembered that there were no explosive phenomena in the vicinity of Lower Conygre Shafts, but at Upper Conygre the gaseous products abounded and rushed out of the Upcast, therefore this must have been the terminal side. Before considering the explosions, it is necessary to observe that, as adequate heat was generated in an explosive ignition, to institute the series of chemical actions that closed in the succeeding explosion, it is unnecessary to consider every explosion, and the terminal points and propagating centres need only be recalled.

Commencing with the distant terminations in the North Branch and Slyving Seam workings, No. 18 Explosion and No. 16 Explosion can be traced back to their origin in No. 15 Explosion, which was propagated by No. 14 Explosion at the Upcast Shaft. No. 14 Explosion and No. 12

Explosion in Pitman's Landing, were propagated from No. 9 Explosion at the junction with Gullick's Incline in the communication, which originated at No. 1 Explosion in Peter's Landing. No. 6 Explosion in Parfitt's Level, and No. 7 Explosion at Barnes' Incline, were propagated from No. 4 Explosion, which with No. 3 Explosion in Parnell's Incline was propagated from No. 2 Explosion, the origin of which was also in No. 1 Explosion at Peter's Landing. All the branches of propagation have therefore a common origin in this explosion: consequently it was the initial gaseous explosion, and the chemical processes, of which it was the ultimate issue, must have entered the field here.

The only remaining avenue to Peter's Landing was the Incline, and the evidences in this direction are as follows:—At the foot of the Incline Carter's body was found burnt, and coked coal-dust deposited on the corner of the refuge hole. The food bag was hanging from the roof forty-four yards outside of the Incline, and had been subjected to intense heat. Coked coal-dust was on the side of the road twenty-eight yards behind the food bag, and six yards in front of the shot that was fired. The side walls of the communication were covered with carbon in impalpable powder, from Peter's Landing throughout this distance to the shot. Forty yards outside of the shot, Carter's clothes and powder canister were found unburnt, and no trace of chemical or physical action was found between this point and Lower Conygre Shafts. The evidences of the action of heat between No. 1 Explosion and the shot, and of its absence from the vicinity of the shot outwards, are therefore conclusive.

There were no disruptive effects in the communication from the foot of Peter's Incline out to the shot; the food bag was still hanging by its cotton tape, and a regulator door between the shot and Lower Conygre shafts was undisturbed. There were some displacements of corner walls and stoppings at the entrances of old roads, in the part of the communication under notice, but they do not affect the point under consideration, and will be dealt with in the Appendix to this volume, with the theory advanced in the Coroner's inquiry, of which they formed the evidence.

The origin of the disaster is now limited to the communication, between Peter's Incline and the Regulator Door. Between these points there were no men engaged except Carter, nor any light burning but that in his possession: and the exclusive operation in progress, was the duty entrusted to him of charging this hole with mining powder and firing it. The shot was fired, the strata it dislodged was upon the floor underneath, and when it is remembered that this was the only operation in the space within which the disaster is seen to have been originated, that it was an operation that would yield adequate heat to set up gas distillation in coal, that the coked residues of distillatory action were present, and that evidence of the generation of heat commenced here, and could be traced to Peter's Landing: the origin of the disaster at the shot is placed beyond question.

The hole containing the mining powder was in the roof of the communication, and bored from the inside, consequently its open end was towards Peter's Incline. It inclined upwards, so that its axis in extension backwards reached the floor of the road within eight yards. The roof at this point was hard stone, and the hole was commenced at a height of 5 feet 6 inches, and bored into a face about 12 inches deep, the under side of which was only 4 feet 6 inches above the floor. The stone was fractured to the root of the hole, and then broke down abruptly, forming an almost vertical face in front and on one side: and feathered off on the other. The products of the fired mining powder meeting resistance to their escape forward at the inside end of the hole, by the almost vertical line of rupture there, would be largely projected back through the line of rupture at the open end, and given a direction corresponding with the declivity of the hole, striking the floor within eight yards. A portion, however, would rush down the abrupt faces at the fast end, reaching the floor underneath, and the remainder would escape through the feathered side. The phenomena of the escaping products in such lines of rupture have been frequently observed in open quarries, where the flames are visible for a moment and are dissipated in the universal atmosphere; but when they are confined in a tunnel, there is not this dissipation; the gaseous and solid products

escape in fan-like sheets, yielding up their heat to the enclosed air, or to the solids that oppose them.

It will be readily conceived how the gaseous and solid products of the fired charge of mining powder under notice, rushed in concentrated sheet form into the coal-dust on the floor of the communication, both underneath the hole, and from six to eight yards distant, and with their unexpended heat energy set up chemical actions, so that in an almost momentary period, the communication here would be the scene of processes of intense potency, which left their effects in coked coal-dust, and the separated carbon that covered the walls.

The quantity of heat that was available for this purpose, depended upon the amount of powder used. The evidence given at the Inquest was that about one pound was placed in the canister for Carter's work, and after the disaster only a "thimbleful" remained, so that the original quantity had been almost wholly disposed of. The hole measured 13 inches long and $1\frac{5}{8}$ inch diameter, and if a cylinder be made of these dimensions and filled with ordinary mining powder, it will be found to hold $16\frac{1}{2}$ ounces. It was not possible to put that quantity into the hole, as space was required for the tamping, without which the stone could not have been ruptured. The hole was bored with a percussion drill by hand, and its fractured wall gave no evidence as to where the pressure commenced in tamping. Allowing for possible waste in making the cartridge (the powder being taken into the mine loosely in the canister), at least $\frac{3}{4}$ lb. of powder remains to be accounted for, and as this was an excessive charge for the hole, further inquiry is needed into the operation.

The examiner, Gage, was instructed by the Bailiff before descending the shaft, to inspect the place where the shot was to be fired, to ascertain if it was in proper condition, and evidently did so, as he passed through it, travelled up Peter's and Wyatt's Inclines, and into Parfitt's Level, interviewed Durham, Bridges, and Harding, and when the disaster happened: he was beyond the places where these men were appointed to work, and over seven hundred yards from the shot. This journey and the duties of inspection of the places, would occupy from twenty-five to thirty minutes: and during this period Carter made the cartridge, charged the hole, carried his tools to a place forty yards outside of the shot,

then returned, lighted the match at the hole, and went for protection to the refuge hole at the foot of Peter's Incline, seventy-seven yards inside of the shot, where his body was found. In travelling to this place he passed two refuge holes—one at fourteen, and the other at thirty-three yards from the shot; the latter was the proper place for him to shelter in; he had already placed his food bag there, and therefore he had some object in walking forty-four yards further. The open end of the shot being towards the refuge holes, the dislodged strata would be driven in the contrary direction, and Carter would have been perfectly safe from any fragments in the second refuge. If the charge, however, failed to break down the strata, and the products were consequently expelled through the hole as a blown-out shot, the heated gases would be propelled in this direction; but with a properly-tamped charge, Carter would have been quite safe in the second refuge, as the flame of the expelled products would not, unassisted, extend one-half the intervening distance; therefore in travelling forty-four yards beyond, he took an unusual step, and extra precautions for his safety.

The conclusion arises from this conduct, that he thought the shot might blow out, and the flame reach an unusual distance: therefore he would shelter himself further away. It is a suggestive fact that he, an experienced man in shot firing, should have feared such an event, and felt it necessary to take excessive precautions to get beyond the reach of danger. There was no room for this feeling had he charged and tamped the hole with the judgment taught by experience. The only possible grounds for any such alarm about this shot, would be that an excessive amount of powder had been put into the hole, and that the tamping placed against the powder was improper in quantity or in character; and only such conditions could have suggested the protection he adopted, because they alone could have brought about the projection of the products of the fired powder, and an extension of flame in the direction in which he retreated. These circumstances, taken with the fact that an excessive quantity of powder was used at this moment, are reasonably conclusive evidence that Carter placed an excessive charge of powder in the hole.

It is recorded that one of the examiners who descended the shaft

with Carter, but who was outside the field of the disaster, warned him not to use tamping with oil in it. Some lumps of plastic material were found near Carter's body, which he had carried there, that permit the suggestion that he had used something of that character for tamping the hole. This material was taken from the floor where the trams rested, and where the lubricating oil dropped off the axles, mingling with the under clay and small coal. It was subjected to examination by Mr. E. H. Cook, D.Sc., F.C.S., at the Clifton Laboratory, and he determined its constitution to be :—

Oil - - -	33·5 per cent.
Coal - - -	43·0 ,,
Mineral mater -	18·0 ,,
Moisture - -	5·5 ,,
	100·0

Upon heating a portion of the material in a closed vessel at 500°C. he found it evolved one hundred times its own volume of gas measured at 0° C and 760 mm. Bar. ; and this gas upon analysis proved to be composed of Methane, Ethylene, and some of the heavier hydrocarbons, with Hydrogen, Carbon Monoxide, and Carbon Dioxide, the composition being very similar to crude coal gas. If Carter did use material of this character for tamping, only a small portion of what was placed in the hole could have undergone decomposition by the ignition of the powder, as Dr. Cook observes : but that quantity must have contributed inflammable gases, and assisted the actions set up in the coal by the products of the powder.

There is no evidence to carry this feature of the case any further ; whether or not the inflammable mixture was used for the tamping, will remain unknown ; but these particulars will serve to exemplify the dangerous character of plastic mixtures taken from the floor of the road in a mine, which must almost necessarily contain coal-dust : and in this instance was found to be impregnated with oil droppings from the tram axles.

Resuming the inquiry into the charge of powder, it will be remembered that an excessive quantity was used out of the canister,

and the question arises as to the object to be gained in overloading the hole. The bed of stone in which the shot was fired, was at its under side only 4½ feet above the floor: and at 10 feet distant the roof was only 4 feet 8 inches high; therefore if the shot could have broken down a thickness of the stone for the whole 10 feet, it would have been an advantage, and made the communication the desired height. There was the necessity, to make the shot break down or loosen the stone, as far beyond the root of the hole as possible. The form in which the stone was ruptured by the shot, showed that this object had been attempted; the strata was broken down to the root of the hole and a little beyond, but the rupture ended in an abrupt and vertically stepped face, showing that more had been attempted than was accomplished, and that the energy in the charge of explosive, had not been wholly expended in excavating the strata.

The circumstances which have been considered in connection with the shot, *viz.*:—Carter's extra precautions to shelter himself from the effects of a blown-out shot, the advantage to be gained by overcharging the hole with explosive, the partial accomplishment of that advantage, and the quantity of powder used out of the canister: are the justification for the statement, that an excessive quantity of powder was used in the hole.

The object Carter had in view was a repetition of what the deceased man Hawkins attempted in the disaster at the Camerton Colliery,[1] and the lines of rupture in the strata were almost identical in the two cases. Hawkins put three inches of tamping into his hole, and if Carter put the same length of tamping into the hole at Timsbury Colliery, then the charge of powder in each case amounted to 12½ ounces, which proved adequate to originate the Camerton disaster.

In his evidence upon the amount of powder necessary for the shot, the Bailiff stated that he should have used about three ounces. The form and cubical measure of the ground broken down by the shot, compares closely with the results of the shot which initiated the disaster at the Camerton Colliery. They were both in the bed of

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[1] "Coal-Dust an Explosive Agent," pp. 12-16.

strata that forms the roof of the Great Seam, and the Collieries, it will be remembered, adjoin each other. The above estimate by the Bailiff of the amount of powder that should have been used at the Timsbury Colliery, is practically the same as the quantity expended in breaking the strata at the Camerton Colliery. Assuming the charge at Timsbury Colliery was, as suggested, 12½ ounces, or three fourths of the amount used out of the canister; and that one quarter, or 3⅛ ounces, were expended in excavation of the strata, the quantities of heat work out as follows: total heat in the combustion of 12½ ounces of mining powder, 183,141 gramme units; allowing one fourth, or 45,785 units, for rock broken, there remain 137,356 units of surplus energy available for the processes which originated the disaster, or the same quantity that was at disposal in the Camerton case.

An important factor in the adequacy of the heat energy, is the condition of the coal-dust. If the dust be dry, the surplus heat is almost wholly available for gas distillation; but if it be wet or damp, the heat has first to be expended in vapourising that moisture, and only the balance that may remain is available for distillation. The hygroscopic condition of the coal-dust in the vicinity of the shot must therefore be considered. The communication, from the Regulator Door to the foot of Peter's Incline, was watered on January 29th, and the space between the rails appears to have been made wet, and in places muddy. The condition of the dust between the side walls and the rails did not attract so much attention. The space between the rails is the travelling track, which bears the attrition wrought by the miners passing over it, and forms a lower level into which the water placed on the outside would naturally drain.

The disaster occurred eight days after the watering referred to, and in the interval the moisture had been exposed to the ventilating current. This current is drawn from Lower Conygre Downcast Shaft, and enters the communication about fifty yards outside of the shot, through the Staple (Plate I.). In ordinary circumstances the current measures 8000 to 10,000 cubic feet per minute; but at the time of the disaster, and for some weeks previously, the external atmospheric temperature had been low, the thermometer not rising to

freezing point by day, and at night the records were as low as 6° Fah. The temperature of the strata of the mine being much higher than that of the external atmosphere, and invariable at that depth beneath the surface, the cold air on descending the Downcast Shaft would be raised to that temperature, and its capacity for aqueous vapour therefore largely increased. Taking the atmospheric temperature at 30° Fah. by day, and 10° Fah. by night, and the strata of the mine at 66° Fah., the relative hygroscopic values of the air would be represented in the following figures[1] :—

Amount of vapour of water contained in

1 cubic foot of saturated air at	10° Fah. =	·8 grains.
,, ,,	30° Fah. =	2·0 ,,
,, ,,	66° Fah. =	7·0 ,,

The air descending the Downcast Shaft would, at the higher temperature of the mine, demand a large accession of aqueous vapour, which it would at once evaporate from all wet or damp surfaces upon which it impinged.

The low atmospheric temperature would also increase the normal difference in the weights of the columns of air in the Downcast and Upcast Shafts, therefore the motive column was made greater, and the ventilation of the mine increased. The sectional area of the communication being a fixed quantity, this larger volume of air would have to travel at a greater velocity.

The normal quantity of air passing through the communication from the Staple to Peter's Incline, was given at 8000 to 10,000 cubic feet per minute. Taking the middle figure of 9000 cubic feet per minute, as the quantity circulating at an ordinary winter temperature of 40° Fah., the quantities at the temperatures under notice, other conditions remaining the same, would be as follows :—

Atmospheric Temperature.	Cubic feet of Air per minute.	Velocity.
40° Fah.	9,000	300 feet per min.
30° ,,	10,590	353 ,,
10° ,,	13,206	440 ,,

The effect of this increased volume and velocity of the air

[1] "Glashier's Tables."

current in the communication, may be conceived by recalling the effect of a dry March wind upon a muddy macadamised road.

An idea may be obtained of the possible evaporation of moisture in the following figures:—

If a current of 10,590 cubic feet of air per minute, at a temperature of 30° Fah., and saturated with aqueous vapour, descended a shaft of the same depth as Lower Conygre, passed through a tunnel like the communication, and issued from it at a temperature of 66° Fah., also in a saturated condition, it must have absorbed 10·181 lbs. of water per minute, or 61 gallons per hour. In the conditions of the ventilation and the workings at Lower Conygre Colliery, the evaporation of moisture in the communication between the Staple where the ventilating current entered, and the foot of Peter's Incline, could only have been a fraction of the above quantity per minute; but the evaporation that was going on incessantly in the interval of eight days, between the last watering of the floor and the firing of the shot, must have reduced this part of the communication to a comparatively dry state; and about 50 tons of coal were conveyed through it on the day preceding the explosion. The coal-dust, especially on the exterior sides of the rails or travelling track, must in such circumstances have been in a favourable condition for distillation; and there could not have been much demand upon the available heat of the mining powder, for the evaporation of moisture.

Previous observations have shown that there was a surplus of 137,356 gramme units of heat at disposal, from the charge of mining powder, after the strata was ruptured: that it was conveyed into the coal-dust on the floor of the communication in the solid and gaseous products of combustion, and that it was available for distillation. This quantity of heat, and its mode of application to the coal-dust, proved adequate to initiate chemical actions, inasmuch as coked residues were found here, and the walls of the communication were covered with carbon, which could only have had its origin in the gases distilled from the coal.

The chemical actions that are now seen to have been originated in the coal-dust in the vicinity of the shot, by the surplus heat of the

charge of explosive, with the evidence of their development and continuity at the food bag, at the Refuge Hole in which Carter sheltered himself, and in the continuous deposition of carbon upon the walls of the communication to Peter's Landing, complete the chain of evidence, which determines the explosive charge to be the originating cause of the disaster, linking it to the explosive ignition in Peter's Landing as the initial gaseous explosion.

The conditions of coal-dust and dryness last discussed, prevailed throughout the field of the disaster, therefore given the quantity of heat generated in the initial gaseous explosion, and the necessary supplies of atmospheric oxygen, the chemical processes already described, must have been repeated in natural course; and propagation of No. 1 Explosion through the mine, would follow irresistibly, as effect follows cause.

Evidences of this propagation were found distributed through the workings, in the form of coked coal, the general deposition of carbon, numerous local violent disturbances betraying identity in character, and preceded by gas generating intervals corresponding to that between the shot and the explosion in Peter's Landing: and ultimately in the smoke, dust, and noxious gases that rushed out of the Upper Conygre Upcast Shaft at the opposite end of the workings.

In the Camerton Colliery Explosion, and in many others where the origin has been traced to shot-firing, the activities originated by the products of the shot were developed in both directions; but at Timsbury Colliery there was no gaseous explosion on the Lower Conygre side, and the circumstances of this failure are instructive.

It will be within recollection that Carter's clothes, tools, and powder canister, were found about forty yards outside of the shot, unburnt (so that the chemical actions at the shot had become extinct before reaching this point, towards Lower Conygre), that the Intake air current entered the communication from the Staple, and that, one hundred and seventy-five yards behind the Staple, there was a Regulator Door, which marked the commencement of the watering. The air current ascending the vertical Staple had to flow over into the horizontal side road, and turn a right angle into the communication

(Plate I.), consequently at this point it would be full of swirls, and would pass several yards along the communication before gaining its full velocity. From this side road to the Staple, back to the Regulator Door, there was no appreciable circulation of air; the door was kept closed by the weight of the column of air in the Downcast Shaft, and any atmospheric movement in it was simply that due to diffusion. There was no mechanical movement in this body of air excepting when men or trams passed through: the effects at the door would be local. The water placed on the floor of this portion of the communication on January 29th would be very slowly subtracted from by evaporation, as the superincumbent air was stagnant, and could not receive from the wet coal on the floor beneath, beyond its point of saturation.

In these circumstances the floor of the communication from a point between the shot and the Staple, and on to the Regulator Door, corresponded, without doubt, with the descriptive phrase used at the Inquest, "Sloppy in places;" while the volume of air in the one hundred and seventy-five yards of *cul de sac* formed by the door, would be saturated with aqueous vapour. In such circumstances any portion of the heat in the products of the shot, or from the chemical actions initiated in this direction, would be first expended in vapourising the water on the floor; and as that wet condition was continuous for a considerable distance, the heat energy would be exhausted at a very early stage. Any educts evolved from the coal-dust into the contiguous atmosphere, would be mixed with the aqueous vapour that atmosphere had already received, and confronted with the cushion of cold wet air in the *cul de sac*; which must have brought about a rapid surrender of heat, so that the temperature would almost immediately fall below the point of ignition and distillation. The educts would at once surrender heat in raising the aqueous vapour with which they mingled, to a condition of steam at a temperature common to both bodies, and this steam would undergo condensation when brought in contact with air or surfaces at a lower temperature. Humid air and wet surfaces were immediately present, and the rapidity with which steam surrenders its heat under such conditions, is illustrated by what takes place in the condenser of a steam engine.

in which the exhaust steam is condensed to water almost instantaneously by contact with cold metallic surfaces, or by the injection of a water spray into the condensing chamber.

It will be seen that these conditions of water upon the floor, and aqueous vapour in the air, were antagonistic to the chemical processes arising in the coal-dust. The effectiveness of such conditions in stopping the chemical actions is due to the fact of the rapidity with which water is converted into steam, and aqueous vapour in the air raised to that condition, at the expense of the heat in the educts in contact with them; and the freedom with which the steam surrenders its heat almost instantly to humid air and wet surfaces; causing a fall of temperature below the point necessary for the chemical actions.

These circumstances provide a significant example of the effect of wet surfaces, and of air laden with aqueous vapour, in arresting the chemical activities in coal-dust, which if not stopped, must cause disaster, and illustrate the value of the accessory precaution adopted in some collieries, of injecting water spray into the air currents in the mine.

THE RATIONALE OF THE DISASTER.

THE evidence advanced in the last chapter of the destructive distillation of the coal-dust, and of numerous small explosions causing local disturbances, and separated by gas generating spaces: provide a basis of facts for enquiring into the origin and nature of the gas that was ignited, and for elucidating the rationale of the disaster. The chemical processes that were in operation between the coal in its normal condition in the vicinity of the shot, and the explosion in Peter's Landing: and antecedently to the successive explosions throughout the field of disaster, will now form the subject of enquiry.

When the coal-dust that is distributed over the road of a mine is subjected to heat, it is raised to a condition of intumescence, and the evolution of volatile matter in a gaseous state is commenced; but if the temperature be inadequate, and the extraneous supplies of heat be not persistent, the distillation will be incomplete, leaving residues of cinder, in which the particles cohere together by virtue of their unvolatilized tarry matter. If the coal-dust be subjected to a higher temperature, and for a sufficient period, in the same conditions of freedom and distribution, the volatile matter will be wholly extracted, and with it the element of cohesion; the solid residue would then be coke in the condition of a granular powder. Both of these residues possess the rough physical character peculiar to coke, and both were discovered in the field of the disaster.

Coal-dust always prevails on the floor of the roads through which loaded trams of coal are conveyed, and it has been shown in the investigation of the explosion at the Camerton Colliery, that the coal-dust on the floor of the South East Incline, and throughout the field of that disaster had undergone distillation. In the Timsbury Colliery it will be remembered that coked residues were found near the floor at the shot, on

the bottom stones of the wall at the foot of Peter's Incline, on the ends of the trams in Wyatt's Landing and the Little Seam Siding, feathering off at twenty-four and twenty-one inches respectively from the floor, the wood-work above those points being clean—on the first prop at the old road in Carter's Incline for eighteen inches above the floor, on the bottom part of an old door in the road to Barnes' Incline, and on the prop in Pitman's Incline. These deposits disclose the fact that the coal-dust on the floor was undergoing distillation, and show that the particles rose up in their educts to a height probably of about twelve inches (the deposits at this height covered the face of the wood, but above it they betrayed the ascensional and spreading effects produced when gaseous bodies collide with fixed and opposing objects); and the obstructions to the progressive movement of this process, retained fragments of coked residues, when the surfaces were favourable for their adhesion.

The quantity of coal acted upon is shown in the coked residues upon the timber near the end of Parfitt's Level, where the process was suddenly arrested, and the intumesced coal undergoing distillation recoiled back into the sphere of past chemical actions (from which the atmospheric oxygen had been removed, and the atmosphere reduced to an attenuated or semi-vacuous state), impelled backward by the cushioned air in the working faces beyond (the exit of which, through the return airway, was stopped by the falls in Parnell's and Wyatt's Inclines), and was deposited in extensive concrete masses on the opposing faces of five successive frames of timber. There was practically no coal-dust upon the side walls and timber in this part of the Level, and these deposits of coked coal in a few yards of road only, will convey an idea of the extensive distillation that was in progress throughout the field of disturbance, consistent with the immense volume of gaseous products that issued out of the workings through Upper Conygre Shaft, for many hours after the disaster.

The gases distilled from coal are necessarily hydrocarbons and hydrogen, with minute quantities of other gases: and it has been supposed by previous investigators, that these gases become ignited and fill the roads with their flame. If this phenomenon did occur, the evidence of such combustion must have abounded. The copious deposition of carbon on the walls of the roads appeared to support this supposition, as the

impingement of such a flame upon these surfaces, would have produced similar effects. A close examination, however, disclosed the facts that this deposition of carbon was largely confined to the side walls of the passages and adjacent materials, and that, comparatively speaking, it was absent from the roof; while the obstructions of wood, stone, and metal in the passages, with which the flame must have collided, and deposited carbon during the contact, bore no trace of it. Further, the flame, having free movement, would inevitably ascend upwards, and upon the cold surface of the roof the carbon must in that case have been copiously deposited; but its comparative absence there, is a fact of observation. The educts of the coal could not therefore have undergone this supposed combustion, filling the roads with flame. The deposition of carbon by a flame impinging upon cold surfaces is due to a surrender of heat, lowering the temperature in that region of the flame, below the point at which carbon is oxidized; and when the enormous area of the side walls and roofs of the roads in the field of the disaster are considered, it will be seen that the temperature of the educts must have fallen below the point of ignition, and the process of distillation become extinct, before the flame could have travelled through an appreciable fraction of the passages. The separation of the carbon and its deposition on the side walls, must therefore have been due to some other action.

The hypothesis that the coal-dust undergoes combustion producing flame (which can only be brought about by the evolution and ignition of its gaseous hydrocarbons), has been so much advanced as an explanation of the Coal-Dust theory, that its consideration must be further pursued with other evidences that are available here.

Gaseous hydrocarbons undergoing combustion, and producing flame, are seen in the ignited gas at an ordinary gas burner, where the carbon constituent is raised to a state of incandescence and oxidized, yielding carbon dioxide. If the roads of the mine had been filled with these gases burning in flame, pronounced effects would have remained upon the timber, trams, and doors, as well as upon the horses, and the unfortunate men. It has been shown that large volumes of gaseous hydrocarbons were evolved from the coal-dust into the passages throughout the field of disturbance, and if they had undergone combustion producing this flame,

the faces of wood must have been burnt and charred, and the bodies of the men and horses cindered, under the action of flame of such magnitude. There were no evidences of this character in the workings; the wood betrayed no indications of the effects of heat; the men were burnt and blackened with coal-dust, but the skin was peeled and not wholly consumed, and their hair, whiskers and moustache, and the hair of the horses, was singed, not burned to the roots: therefore they could not have been attacked by flame.

The combustion of gaseous hydrocarbons at the *locus*, and at the moment of their evolution, exerts no more mechanical force than is exhibited in a burning gas jet; consequently the isolated and widely separated exhibitions of violence over the field of the disaster, would be as inexplicable upon such an hypothesis as they are inconsistent with it. The disconnected exhibitions of violence are facts of observation, and an adequate cause for them must find a place in the rationale of the explosion.

Finally, the combustion of the gases under consideration produces well known products, carbon dioxide being one of the principal bodies, which immediately reveals itself by its effect upon the lights.

Favourable opportunities occurred immediately after the disaster for discovering whether this gas had a place in the products of the explosions. The ventilation of the workings was suspended by the destruction of the ventilating doors, and the collapse of the air roads; consequently the gaseous products of the oxidations that had occurred, were trapped and locked in between successive falls. The rescue parties made openings through the falls, and, in their anxiety to rescue the miners, repeatedly advanced into these gaseous products, and their candles burned as brightly in them as they did in the pure air. Dr. Angus Smith showed, many years ago, and it has been confirmed by recent investigations, that an atmosphere containing about 2 per cent. of carbon dioxide extinguishes a light: therefore the evidence in the burning candles of the rescue parties, proves that it was absent, and that the carbon of the gaseous hydrocarbons had not undergone oxidation.

Either of these evidences of the absence of the effects of flame upon inflammable bodies, the presence of numerous exhibitions of

violence, or the non-existence of carbon dioxide: are sufficient to show that the coal-dust, or in other words the carbon of its gaseous hydrocarbons, did not undergo combustion; but together they leave no room to question this conclusion.

The phenomena in the mine must be again considered, for evidence of the actions which were in progress in the gaseous hydrocarbons. It will be remembered that the effect of the heat upon the coal-dust lying upon a plank of Carter's Stage, 4 feet above the floor, was to produce from it a coked deposit in flakes of fish-like form, which were loose upon the wood. It is conceivable that these particles of coal-dust, might have risen with their educts in suspension in the hot gases that attacked them, and become displaced, or have been carried away by their onward movement; but the presence of their residues on the plank indicates that the hot gases ascended from below, and that the educts moved forward at a slow velocity; while the coked condition shows that the gases were at a high temperature, and effected distillation, not combustion.

The loaded tram of coal, near the end of Parfitt's Level, may also be recalled. The tram stood 2 feet 6 inches above the rails, and had been loaded only a few yards away, so that the coal had not settled down in transit, and the blocks stood from fifteen to eighteen inches above the wood work, consequently the top surface of the coal reached a height of about four feet. The condition of these blocks of coal all round the tram, showed that they had been enveloped in a gaseous mixture at a high temperature, which had attacked their solid and hard faces, causing them to burst out into globules of bituminous matter, which underwent further destructive distillation, leaving residues of comminuted coke. A few of these globules remained attached to some of the faces of coal, but on every ledge of coal or tram where they could rest, there were accumulations resembling coarse sand, while there was no coke or partially coked coal-dust on the roof over the tram. This comminuted coke disclosed a perfect exhaustion of the volatile constituents of the coal on the loaded tram; but the coal-dust residues exhibited only partial distillation, as was observed in the concrete residues on the timber only a few yards distant in the Level, and on the timber at Carter's and Pitman's

Inclines, as well as on the trams in the Little Seam siding, and Wyatt's Landing, on the wall at Peter's Incline, and on the floor near the shot, although the coal-dust in all these places was by virtue of its fineness of division, in a far more favourable condition for perfect distillation, than the blocks of coal. All these coked residues were in the same field of distillatory action, and there could have been no appreciable variation in the period of those actions; consequently the perfect distillation of the coal on the loaded tram, indicates a much higher temperature than the imperfect distillation of the coal-dust, which left sufficient tarry matter behind, to cause the coherence of the particles, and their adhesion in masses to vertical faces of timber.

The distillation of the coal upon the tram, must have been effected by the educts from the coal-dust upon the floor: as the accumulations of comminuted coke upon the blocks of coal, and which had gravitated downwards from ledge to ledge as they were produced, show that there was no horizontal movement in the gases at this point, otherwise these fine particles of coke would have been carried away. When the educts of the coal dust rose from the floor, they would be at the temperature due to that early stage of distillation which produces only partial volatilization of the tarry matters, or in other words the temperature of the solid residues; but when they reached the coal on the tram, at a height of $2\frac{1}{2}$ to 4 feet above the floor, they effected the complete distillation of the faces of blocks of coal, which represents the higher temperature due to the perfect stage of distillation. Consequently the educts had gained an elevation of temperature between the floor and the top of the tram, and must have been themselves the subject of chemical actions to have brought about this increase of heat; and the nature of those actions has now to be sought.

The depositions of carbon, and the residues of coke, represent different states of the same substance, the former being impalpable and fine like flour, the latter coarse and hard like cinder. In the conditions existing here of exclusive distillation of coal, this carbon and coke must have had their origin in different bodies, as they could not be both produced in the distillatory action. The coke is at once recognized as the solid residue of the destructive distillation of coal, and the

carbon is also distinguished as being identical with the solid constituent of the evolved gaseous hydrocarbons, and produced by their partial combustion or dissociation.

In the gaseous hydrocarbons that filled into the workings, there was unquestionably an adequate source for the deposition of carbon, both in quantity and in distribution: and in seeking to know the process by which it was separated in an unoxidized form, it must not be forgotten that the educts gained an elevation of temperature in this separation.

It has been already shown that there was not any appreciable combustion of the gaseous hydrocarbons, and as the temperature at command was one of ignition, as is seen by the ignitions in each explosion at the end of the gas generating spaces, it is manifest that the remaining factor of oxygen was not within their reach, so that combustion could not take place. The tram of coal in Parfitt's Level affords further confirmation; as if the gaseous body that enveloped the tram had been able to obtain oxygen, the effects of the combustion that must have ensued, would have abounded on the tram, coal, and roof; but there was no trace of it. The absence of combustion proves that the supplies of atmospheric oxygen were too limited, or that they were not within reach of the gaseous hydrocarbons. In these circumstances, the secondary actions which are seen to have had a place in the educts, could only have obtained limited supplies of oxygen, probably from interstitial spaces and side roads, but sufficient to oxidise the hydrogen constituent of a portion of the gaseous hydrocarbons. This oxidation of hydrogen would generate large quantities of heat, and necessarily produce the observed elevation of temperature.

In the process of the oxidation of the hydrogen, the solid or carbon constituent could not be converted into carbon dioxide because there was no oxygen for that purpose, therefore it was unchanged, and deposited in the unoxidized condition in which it was found; and the temperature due to the oxidation of hydrogen being considerably higher than the temperature of dissociation of gaseous hydrocarbons, the remaining portion of those gases would be decomposed, yielding

further quantities of their carbon for deposition on the walls of the mine. The deposition of carbon, and the elevation of temperature, have their explanation in the conditions that are shown to have been present, and the origin of the carbon is traced to the gases of which it was a constituent, and which the coal-dust had yielded.

This hypothesis of the partial oxidation of the gaseous hydrocarbons, is therefore seen to afford a complete explanation of the occurrence of the extensive deposition of carbon; and of the facts, that the gaseous products in the explosions that were trapped between the falls, were laden with this carbon in suspension, and the gases that rushed out of the mine through Upper Conygre Upcast Shaft were so charged with it, that the term "Smoke" was employed to designate their condition.

In the Ohio Petroleum regions of America, large volumes of gaseous hydrocarbons are naturally yielded by the bore holes, and some portion is dealt with for the purpose of obtaining the carbon constituent, which forms the subject of this inquiry. Those hydrocarbons are made to burn under conditions, in which the hydrogen constituent only is oxidized, and the carbon is separated in a solid state: forming the article of commerce known as "Diamond Black."

The hypothesis first advanced in the investigation of the Camerton Colliery Explosion, of the orign of this impalpable carbon,[1] and further developed in this work, has therefore its fulfilment in industrial operations, and conclusive evidence has now been advanced that it correctly accounts for the deposition of carbon in the field of the explosions.

The activities that are seen to have prevailed over the large field of disturbance could only have been sustained by constant supplies of heat, and these demands must form the next subject of inquiry.

The initial gaseous explosion was 191 yards from the shot, and therefore continuous supplies of heat were necessary to sustain the distillation of coal through this distance, and provide an ignition temperature at the end. The surplus heat available from the

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[1] "Coal-Dust an Explosive Agent," pp. 53-55.

charge of mining powder has already been estimated at 137,356 gramme units, the gaseous products containing 72,744, and the solid 64,612 units. There was no evidence of any expenditure of this heat on the Lower Conygre side of the shot, and the above surplus may therefore be taken as used on the side of No. 1 Explosion, where, in the absence of any other supplies, it must have:—

(a,) Raised 187·677 grammes of the mining powder to the temperature of ignition of the gaseous mixture.

(b,) Distilled gases from the coal-dust.

(c,) Raised a portion of the distilled gases to the temperature of ignition.

(d,) Raised the volume of air required for the oxidation, to the ignition temperature.

(e,) Supplemented the losses of heat in the gaseous mixture by its contact with about 10,000 square feet of cold surfaces.

The specific heat of the gaseous products of combustion of mining powder was determined by Sir Frederick Abel and Sir Andrew Noble, at ·09553[1] and the ignition temperature of hydrogen being 650° C, the first item is:—

$$187{,}677 \times {\cdot}09553 \times 650 = 11{,}650 \text{ gramme units.}$$

The quantity of gas yielded by the coal may be taken as approximately represented by the analysis of the coal at the Camerton Colliery,[2] as the Collieries adjoin each other, and the coal seams are identical. The distillation proceeded over 191 yards of road representing about 3438 square feet of floor surface, upon each square foot of which the small coal and coal-dust would average about four or six ounces: and if two ounces only were distilled, that would equal 430 lbs. over the area. The coal yields over 11,000 cubic feet of purified gas per ton, and assuming that the incomplete distillation exhibited in the concrete coked residues upon the timber, represented the extent to which the volatile matter was extracted, it would be safe to estimate that the 430 lbs. of coal yielded 1000 cubic feet of hydrogen. The conditions under which this distillation proceeded are

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[1] "Philosophical Transactions," vol. clxxi, p. 228.

[2] "Coal-Dust an Explosive Agent," p. 45.

only partly known, and therefore it is difficult to estimate the expenditure of heat under this head.

Having regard to the disruptive effects in Peter's Landing, it may be reasonably estimated that one half of this quantity of hydrogen was exploded there. The specific heat of this gas at equal weights, water being unity, is 3·409, and 500 cubic feet at 0·C and 760 m.m. bar pressure weigh 1267·84 grammes, therefore the third computation is :—

$$1267{\cdot}84 \times 3{\cdot}409 \times 650 = 2{,}809{,}343 \text{ gramme units.}$$

The 1267·84 grammes of hydrogen will require 10,142 grammes of oxygen for its oxidation, which could only be obtained from the air, and therefore in association with 33,956 grammes of nitrogen. The specific heats of oxygen and nitrogen at equal weights and constant pressure are ·2175 and ·2438 respectively, therefore the fourth item is :—

$$10{,}142 \times {\cdot}2175 \times 650 = 1{,}433{,}825$$
$$33{,}956 \times {\cdot}2438 \times 650 = 5{,}381{,}007$$
$$6{,}814{,}832 \text{ gramme units.}$$

It is unnecessary to pursue the computations further, as the three items *a*, *c*, and *d* (11,650 + 2,809,343 + 6,814,832) alone demand 9,635,825 gramme units of heat, while the total quantity from the mining powder, is only 137,356 gramme units; therefore the absolute failure of the powder to supply the demands for the initial gaseous explosion is demonstrated, and the sources of the supplementary supplies that are now shown to have been necessary, must be sought elsewhere.

It will be within recollection that there was an elevation of temperature observed in the educts of the coal, and that the hydrogen constituent of some of the hydrocarbons was oxidized. The estimated quantity of hydrogen produced was 1000 cubic feet, one-half of which was considered to have been required for No. 1 Explosion, therefore the remaining 500 cubic feet would be available for oxidation between the shot and that explosion ; and require 250 cubic feet of oxygen for that purpose. The normal quantity of air in this length of communication would exceed 20,000 cubic feet, containing over 4000 cubic feet of oxygen ; therefore it is readily conceivable that the 250 cubic feet of oxygen required for the oxidation of the hydrogen under notice, would be obtainable here.

The oxidation of one gramme of hydrogen produces 34,462 gramme units of heat, consequently 500 cubic feet or 1267·84 grammes, will generate in round figures 44,000,000 gramme units, which would supply the demands of 9,635,825 units under heads *a*, *c*, and *d*, leaving over 34,000,000 units for the requirements under *b* and *e*.

The supplementary sources of heat that were essential to produce the initial gaseous explosion, are therefore found in the series of chemical actions that must have filled the space between the shot and that explosion. The deposition of carbon on the walls of the communication throughout this distance, is demonstrative evidence that this constituent of the gaseous hydrocarbons was separated and unoxidized; but that separation could only be brought about by the oxidation of the hydrogen constituent, therefore the evidence is conclusive that supplementary supplies of heat were uninterruptedly generated from the shot to No. 1 Explosion. The sufficiency of those supplies to meet the demands that have been laid down, is seen in the enormous quantity of heat generated in the combustion of hydrogen: and the ignition temperature at the centre of No. 1 Explosion is also found in the chemical activities which are seen to have been continuous to that point.

The product of the combustion of hydrogen being water in a gaseous state, which is immediately condensed in the conditions that were present, it is almost impossible to find evidence of that combustion in the passages. There were, however, two features of interest that may be recalled, and one was the dry condition of the walls and timber in the mine, brought about by the atmospheric temperature being very low for several weeks before the disaster, and which has been explained upon a preceding page.[1]

The deposition of carbon on the walls and timber was so copious that it could be scraped off, and the adherence of this carbon to vertical and previously dry faces of stone and timber, and to such a thickness, suggested that some abnormal condition had arisen in the disaster which had made these surfaces adhesive, and caused the particles of carbon to cohere together upon contact with each other. When the hydrogen was

[1] Ante, pp. 45-46.

oxidized, the first part of the product would immediately liquify in the air of the passage, saturating it with condensed steam, and the particles of carbon which in the preceding moment had been disseminated in the atmosphere, would be enveloped in this steam, and must have become coated with some of the moisture, which would promote their coherence when deposited.

Another portion of the product would condense upon the surface of the strata and on the timber, making them moist and adhesive, so that the particles of carbon would stick; and these particles being slightly coherent by virtue of the water vapour with which they had been impregnated while in suspension in the atmosphere, would become attached to these vertical faces in successive accretions, and produce the thick deposition that was observed.

This deposition of carbon was co-extensive with the oxidations throughout the field of the disaster, and the very extensive surface area of the side walls and timber of the passages upon which it was observed, will convey an idea of the large quantity of water that must have been produced in a gaseous state, and condensed upon those surfaces, to have brought about a condition capable of holding such depositions of carbon.

The other feature was the large area of drops of water thickly studded over the roof at the bottom of Parnell's Incline, which has been already described.[1] The workings being here very dry, the moisture that exudes from the strata and roof when first broken, having been all evaporated years ago, there was no natural source from which this water could have been drawn, and it was not there when the Author visited the place a fortnight previously. It is therefore beyond question that these drops of water, were condensed products of the oxidations of the hydrogen in the explosion and the adjacent chemical actions, at the top of Parnell's Incline, and represented that part which came in contact with the cold stone roof, while no doubt a much larger portion escaped into the air current in Wyatt's Landing. This large surface of sixteen square yards thickly covered with drops of water, affords

[1] Ante, p. 35.

further evidence that water vapour was the predominant gaseous product of the explosions and antecedent chemical actions: and the foregoing phenomena are interesting for the demonstration they afford of this branch of the rationale of the disaster.

The temperature of hydrogen undergoing oxidation is about 2000°C, but all the gaseous hydrocarbons are dissociated at temperatures under 1500°C, therefore the remainder of these gases whose hydrogen was not oxidized, would at this temperature be dissociated, filling the atmosphere of the passages with carbon and free hydrogen, and providing the gas for the explosive ignition.

The origin and distribution of the flocculent carbon, the sources of the supplementary supplies of heat, and the origin and nature of the gas that was ignited in No. 1 Explosion, have now been elucidated; and it will be recognized that the processes which have been disclosed by an investigation of the phenomena, reveal the nature of the series of chemical actions which were originated in the coal-dust by the heat from the mining powder, and that were closed in the explosion in Peter's Landing.

The propagation of No. 1 Explosion will now present no difficulty, as it is only necessary to recall the series of chemical actions that produced the initial explosion, to recognize the fact that No. 2 Explosion would be brought about by a repetition of this series of actions; and when it is known that the heat that originated the disaster at the shot, represents that due to the oxidation of less than four grammes of hydrogen, and that the 500 cubic feet suggested to have been ignited in No. 1 Explosion would generate more than three hundred times that quantity, an idea will be gained of the enormous resources of heat that were now available, for reinstituting the activities and propagating the explosion throughout the mine.

The explosions were propagated at irregular intervals, and it was observed that they occurred where the roads expanded into large sectional areas and provided the necessary supplies of atmospheric oxygen. The explosions numbered 1, 2, 3, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, and 18 were in landings and junctions, No. 4 was in a *cul de sac*, and Nos. 8 and 17 where there were open spaces in the roof.

The variations in the exhibitions of disruptive force that characterize the explosions, have their explanation in the quantities of explosive gas that were oxidized, or, in other words, in the quantities of oxygen that were obtainable: as the coal-dust from which the hydrogen was obtained was largely in excess of the quantity that was subjected to distillation. The greatest disruption was in No. 1 Explosion in the main Intake air, and in No. 14 Explosion at the Upcast Shaft, where the Intake air from the Downcast Shaft rushed in and supplied the chemical actions, the separation door having been destroyed. The least disruptions were in No. 6 Explosion at the foot of Carter's Incline, No. 7 Explosion at Barnes' Incline, No. 16 Explosion in the Slyving Seam, and No. 18 Explosion in the North Branch: all of them being in impoverished air or small currents; and an examination of the other explosions shows a correspondence between the disruptive effects and the condition of the air currents, or the quantities of oxygen they were able to supply for the oxidations of the hydrogen.

The explosive phenomena were continuous into the neighbourhood of the coal faces on one occasion, and on others they ended abruptly in the main roads, though coal-dust was present in all the places; and this feature has been advanced as a difficulty, and an argument for the rejection of the theory, that coal-dust will yield up its gases and cause an explosion. This argument appears to rest upon a misconception of the conditions necessary to an explosion. It is a matter of common knowledge that if an explosive gas be mixed with air in proper proportions, it is harmless so long as a light is excluded; and it is equally true that if one element be substituted for the other, and the light taken into the gas from which all air is excluded, or into the air which has no gas mixed with it, the effect would also be innocuous; but if the gas, air, and light be brought together, an explosion is the result. The three elements gas, oxygen, and heat are essential to complete the explosive cycle, and these conditions afford the solution of the difficulty under notice.

When distillatory action is instituted in the small coal upon the floor, the mine passage at that place is filled with the educts and their derivatives: and so long as the passage is of a comparatively uniform section, and

there is no fixed obstruction to the free movement of the air, the distillatory action continues through considerable distances, and there is no explosive ignition of gas. One of the elements of the explosive cycle must therefore have been unobtainable in these conditions, and as the gas and the heat were there, it is evident that the necessary oxygen was not present. When, however, the educts and their derivatives emerged from a normal section of passage into a larger space, they obtained the necessary supplies of oxygen, and the ignition temperature being present in the distillatory action, or in the partial oxidation proceeding in the educts, an explosion followed. Exceptions sometimes arise, which provide their own explanation. It is a fact of observation that the exhibitions of explosive force were found in or near to the large sectional areas of the workings, where ample supplies of oxygen were available, with the following exception: —Where a ventilating door was fixed, which closed in the direction in which the educts and their derivatives were travelling, it formed a *cul de sac*, into which they advanced, compressing the contained air until its tension exceeded that of the educts, when the concentrated oxygen mixed with the gases and explosive combustion followed.

The cessations of the explosions in the presence of coal-dust, afford further illustrations that oxygen was not always available, and that to its absence the failures in propagation were due. The conditions that prevailed at the end of Parfitt's Level have been described,[1] and it will be remembered that the coal there was undergoing distillation at an elevated temperature, and that the educts and their derivatives had reached a large space, but no explosion occurred; both the tram and its coal were undisturbed, in contrast with the confused mass of broken trams and scattered coal in Parnell's and Pitman's Landings, where explosions had taken place. Explosive gas, and an ignition temperature, were present at the tram in Parfitt's Level, therefore the absent element must have been oxygen. The collapse of Peter's Incline caused by No. 1 Explosion, stopped the In-take air current. No. 4 Explosion in Parfitt's Level destroyed the ventilating doors there, and the In-take air that may have been in the "Tunnel," instead of circulating into the end of the Level,

[1] Ante, pp. 20, 21.

escaped back direct to Wyatt's Incline. The oxygen in the air already in the Level beyond the doors, to the foot of Carter's Incline, had been exhausted by the demands of No. 5 and No. 6 Explosions and the processes that preceded them, and the atmosphere left there comprised their products and the inert nitrogen. It is therefore manifest, that with the supply of In-take air cut off, and the stores of air in the Level exhausted or impoverished, there could not have been an appreciable quantity of oxygen left for the oxidation of the explosive gas, therefore an explosion was an impossibility. The No. 7 Explosion at Barnes' Incline, which undoubtedly preceded the phenomena at the end of Parfitt's Level in point of time, occurred in the Return air current from that Level, and the failure in propagation here, was in impoverished air.

Nos. 11 and 12 Explosions at the top and the bottom respectively of Pitman's Incline, were in a Return air current which had ventilated a district of workings on the Great Seam, consequently its oxygen must have undergone a sensible exhaustion, and in this condition No. 11 Explosion failed to propagate in the small split of air into the Slyving Seam workings; and No. 12 Explosion in the main air current beyond the Incline. No. 13 Explosion in the communication, was in the combined Return currents of Wyatt's and Pitman's Inclines, and failed to propagate into the Little Slyving Seam workings which were ventilated by these currents. No. 16 Explosion in the Slyving Seam was in the split of the Return air at Pitman's Incline above described, and failed to propagate, because the products of No. 11 Explosion and the inert nitrogen had already reached the faces there, but were prevented by the doors from diffusing to the point where No. 16 Explosion occurred. No. 18 Explosion was in a small split of air returning through the North Branch, and failed to propagate into the Top Little Seam workings there, or into the North Branch beyond.

This feature of the cessations of the explosions in the neighbourhood of the coal faces and in the main roads, therefore has its explanation in the absence of sufficient supplies of atmospheric oxygen; consequently the failures of propagation, or the abrupt terminations of explosive phenomena in the presence of coal-dust, is due to the condition of the ventilating currents, and the difficulty under notice, in accepting the theory that coal-dust is itself a potential danger, must disappear.

It will now be understood that if the air in the passage be that of the Return current, the oxygen of which has been partly used in ordinary oxidations, and to which the gaseous exhalations of the mine have been added, it cannot supply the oxygen for the partial oxidation in the educts, upon which the supplementary supplies of heat depend; and in that case the chemical actions including distillation must cease.

Gas distillation can be no more carried on in a mine, than it can be effected in the gas retorts, unless it is constantly sustained by extraneous supplies of heat; and adequate supplies of atmospheric oxygen are indispensable for the generation of that heat.

Finally, the condition of the ventilating currents in supplying oxygen for the chemical actions, is illustrated by the coked residues, or their absence. The air in Parfitt's Level was the main In-take current, which in ordinary circumstances measured 8000 to 10,000 cubic feet per minute, and it will be remembered that there were masses of coked coal on the timber a short distance from the coal faces. The air in all the other terminations of the disaster were the Return or impoverished currents, and, with the exception of the Slyving Seam, these terminations were considerable distances from the coal faces; and in no case was there any appreciable deposit of coked dust visible. The distillatory actions had at these points, shrunk to the vanishing point. Coal-dust was present, and the suspension of distillation could only be brought about by the discontinuance of the supplies of heat. The only possible source of these supplies was oxidation in the educts, which absolutely depended upon adequate resources of atmospheric oxygen; and these not being obtainable, the oxidation ceased, the distillatory actions broke down, and the explosive phenomena ended.

The essential conditions in the propagation of explosive phenomena have been considered, and it has been shown that the three elements of coal, heat, and oxygen, must be present; and that however abundant the first two may be, in the absence of adequate supplies of the latter, the whole of the activities must fail.

The absence of carbon dioxide in the products of the explosions and antecedent processes, finds its explanation in the fact, that the carbon constituent of the gaseous hydrocarbons, by the oxidation of which carbon

dioxide could alone be produced, was not oxidized, but separated and disseminated in the atmosphere of the workings; one part being deposited on the walls and timber, and the remainder swept out of the mine by the restored air currents.

The only processes by which this separation of the carbon could have been brought about, was the oxidation of the hydrogen constituent, and dissociation at the temperature that would be then present; and both actions were essential to the observed uninterrupted deposition of carbon, and the provision of bodies of free hydrogen for the explosive ignitions.

This oxidation in the educts generated supplementary supplies of heat, without which the explosive phenomena would have terminated with its inception in the vicinity of the shot.

The hypothesis of the oxidation of the hydrogen constituent of some of the gaseous hydrocarbons, which was first advanced by the Author, in his investigation of the Camerton Colliery Explosion, ("Coal-Dust an Explosive Agent," pages 59, 85, 86, 88, 89, 91), and further developed in this volume, to explain the carbon in suspension in the atmosphere of the mine, the deposits upon the walls and timber in the passages, the smoke that issued out of the shaft, and the nature of the products of the oxidation of the gases; and to provide the supplies of heat that were proved to be essential to bring about the explosions, is now demonstrated to have had a place in the rationale of the disaster.

The evidences of the explosion have now been investigated, and an effort made to elucidate its origin by tracing the phenomena back stage by stage to their causes. These investigations have disclosed the inception and rationale of the disaster, which may be shortly stated as follows:—

The unexpended heat in the charge of mining powder, was projected into the small coal and coal-dust on the floor in the vicinity of the shot, and instituted distillatory action in which gaseous hydrocarbons, with probably some free hydrogen and minute quantities of other gases, were evolved. These educts were at an ignition temperature, but could only obtain small quantities of oxygen, that proved inadequate to oxidize the carbon constituent, which therefore remained unchanged. The limited supplies of oxygen were seized by the hydrogen constituent of some of

the hydrocarbons, and used for its oxidation, the carbon being set free in solid form. The oxidation of the hydrogen generated large quantities of heat, and raised the educts to an exalted temperature, at which the remaining hydrocarbons were dissociated; and the distillatory action was sustained, and dissociation was continued, through considerable lengths of the passages. The separated carbon filled the atmosphere of the passages, and was deposited on the side walls or timber, or escaped out of the mine in the products of the oxidations. The free hydrogen formed the explosive gas, which, on reaching a place in the mine where it could obtain the necessary oxygen (and an ignition temperature being at hand in the partial oxidation in progress), was oxidized, causing a violent local explosion, which exerted disruptive force in all directions.

This local explosion generated an immense quantity of heat, which reinstituted the series of chemical actions in a further length of passage, and a second explosion occurred at another point beyond, when the cycle was complete. These processes were repeated again and again, explosions following upon the completion of each series of the activities; and presented the phenomenon of distinct explosions of hydrogen gas: separated by gas generating intervals, throughout the field of disturbance, so long as coal-dust prevailed, atmospheric oxygen was obtainable for the oxidations, and wet surfaces were absent.

CORRELATIONS OF EXPLOSIONS IN GASEOUS AND NON-GASEOUS MINES.

THE Timsbury Colliery disaster presents the fullest and most diversified phenomena yet known, of an explosion in a mine free from fire-damp, and affords additional teachings to those in the Camerton Colliery Explosion. Although there were slight variations in the developments of these disasters, they were identical in their fundamental characters. Both were in non-gaseous mines, and originated in shot-firing operations, the heat produced by the ignitions of the explosive being unintentionally thrown into the coal-dust of the mine. The amount of explosive placed in the respective holes, the character and extent of the work that was accomplished by its ignition, and the quantities of unexpended heat, were approximately the same; and this heat was projected in the products of combustion into the coal-dust on the floor or sides of the passages. There were residues of coked coal where these products collided with the floor and side. A short distance away food bags which had been left hanging from the roof had been subjected to high temperatures; further away, the men who fired the shots were found burnt, and beyond them violent gaseous explosions had occurred. These explosions were not heard by survivors in the workings, they were local in character, and were repeated with intervals of time and space throughout the fields of the disasters, always occurring at or near to large sectional areas of passage, or where the necessary supplies of atmospheric oxygen could be otherwise obtained. Trams, doors, timber, and loose materials were crumpled, broken, or shattered to fragments, and the passages were more or less wrecked at the *loci* of these explosions; but in the intervals between them, there were no evidences of disruptive force; trams, timber, and loose materials were undisturbed and undamaged. Disruptive forces were exerted in opposing directions and in transverse

openings equally, at the centres of these explosions, and the effects ceased within short distances. Blocks of coal on loaded trams were attacked, and their volatile matter distilled out; coked residues were found at numerous and widely-distant points, and copious deposits of impalpable carbon covered the side walls throughout the fields of the disasters. The gaseous products in the explosions were heavily charged with particles of this carbon, gases laden with it were observed to issue out of the Timsbury Colliery Upcast Shaft for several hours, a feature corresponding with what has been generally seen at gaseous mines after explosions. This phenomenon must also necessarily have been present at the Camerton Colliery Upcast Shaft, as the atmosphere in the workings, which was forced out of that shaft, was laden with carbon; but there was no observer there to record it. At Camerton Colliery a wet length of road stopped one of the propagations of the explosion; at Timsbury Colliery a length of wet floor and air laden with water vapour, arrested the disaster at its inception, on one side of the originating shot. In both mines propagations failed in Return or impoverished air currents.

The lights of the Rescue parties burned as brightly in the gaseous products that filled the workings after the disasters, as they did in the pure air, and the physical sensations experienced by members of the parties, afforded them the only indication of the difference in the two atmospheres. These sensations were giddiness, headache, smarting of eyes and nose, and rapid loss of power; and members of the Rescue parties had frequently to retreat back to where the fresh air was circulating, and on several occasions many of them had to be carried back to be restored to consciousness.

The identity of the phenomena of the disasters at the Camerton and Timsbury Collieries is a fact, the importance of which can scarcely be over-estimated. These mines were free from fire-damp, and the disasters have been proved to be due to the explosive ignition of gas, derived from the coal-dust that prevailed throughout the workings. The origin and rationale of explosions not complicated by the possible presence of fire-damp is now known, and a body of evidence is available for investigating the explosions in gaseous mines, and of discovering whether they

were due to fire-damp, which was supposed to have suddenly appeared in large volumes, or to the coal-dust, always and everywhere present.

When explosions have happened in gaseous mines, it has almost been a foregone conclusion, that they were caused by the explosive ignition of fire-damp; and although coked residues of coal-dust were observed in the Haswell Collieries after the explosion there in 1844, and recognized to have been a contributory agent in yielding gas in that calamity; and coked residues have been observed in most of the explosions since that date, there has been a great weight of opinion up to a very recent period, that the disasters in these mines were due to fire-damp, and that if the danger of the ignition of that gas could be provided against, these mining calamities would be at an end. This opinion has been challenged during the present and a part of the previous decade, and the hypothesis advanced that coal-dust was a principal agent in propagating an explosion of fire-damp. In recent years this hypothesis has been developed into the suggestion that these calamities could be produced from coal-dust alone.

These respective theories of fire-damp and coal-dust, necessarily rested upon the evidences that could be presented in their favour, and which were contained in the records of the explosions; but these records were claimed by both sides as supporting their cases, and proved to be too general in their character to admit of conclusions being reached. The Messrs. W. N. and J. B. Atkinson, H.M.'s Inspectors of Mines, then published more detailed observations of the effects produced in several explosions in Durham, and their work, entitled "Explosions in Mines," added largely to the information upon the subject. The evidence was, however, still inadequate to justify a decision; but the case in favour of coal-dust was considerably advanced.

The minute observations of the explosions in two non-gaseous mines, and the interpretations of their phenomena which investigations have yielded, have proved absolutely that calamities are produced from coal-dust; and, with these evidences, the Author now proposes to examine the recorded phenomena of explosions in gaseous mines.

The recent disaster at the Albion Colliery first demands attention, as it is the greatest calamity that has occurred during the last quarter

of a century, and after a protracted inquiry, in which fifty-four witnesses were examined, there remained a strong division of opinion as to its origin, both in cause and locality. The managing staff and many mining engineers of great experience, contended that it originated in the Cilfynydd Level about one hundred and forty yards from the Downcast Shaft; that it was caused by an outburst of gas from the roof, and its ignition at the Comet lights burning in the vicinity. The five Inspectors placed its inception in Grover's Level, about six hundred yards on the opposite side of the Shaft, and held that the cause was in shot-firing at that point, which "Ignited fine coal-dust directly or a small accumulation of gas over the timbers, which in its turn ignited the dust in the vicinity."[1] The result of the investigation was that the jury decided there had been "An explosion of gas . . . accelerated and extended by coal-dust," but disagreed as to the place of origin.

The evidence advanced of origin in the Cilfynydd Level, was a fall of roof found there after the disaster, and the directions in which timber and materials had been displaced. The inception in Grover's Level, was also founded upon the directions of force betrayed by the disarranged timber. The directions of force suggested by the disordered materials were equally claimed for each hypothesis, and are described by the Inspectors and Mining Engineers alike, as "Complex" and "Conflicting." The employment of these terms as descriptive of natural phenomena, is based upon the preconception that the explosion was a "Blast" rushing inwards and outwards from its origin, each branch maintaining uniformity of direction, and "Carried forward by the continuous train of dust." Upon this hypothesis the materials would be displaced in the directions in which the "Blast" travelled: but they were frequently found thrown in opposing directions, both with and against the course of the supposed "Blast"; and therefore these indications of force in contradictory directions, were argued in support of both contentions as to the place of origin. The intervening space of about seven hundred and forty yards between the suggested *loci* of inception, betrayed these diversified

[1] "Reports on the Disaster at the Albion Colliery," p. 37.

indications. The timbers are reported as "Blown in both directions . . . inwards and outwards."[1] The Engine in Grover's Level was supported upon four beams. "The first beam on the side towards the shaft had been lifted . . . by a force coming from the pit, because the three other beams were not disturbed. A pulley under one of the beams, and attached by two arms, had been blown inwards."[2] "The masonry work of the boilers on Grover's side was blown from the Intake towards the Return, whereas that of the boilers on the Cilfynydd side was blown from the Return to the Intake."[3]

In the Cilfynydd Level on the opposite side of the shaft, the following indications are reported. "In the Cilfynydd Engine house, a signal knocker was blown outwards, part of the staging was blown outwards . . . indicating force outwards; a strap for holding the catches was bent towards the face indicating force inwards." "The Engineer was blown four or five yards outwards." "Three pulleys holding the tail rope were bent, two outwards towards the pit, and one inwards." "A journey of twelve or fifteen trams on the pit parting was blown in both directions."[4]

The foregoing evidences directly oppose the hypothesis of a continuous "Blast." The disruptive displacements of materials in opposite directions relatively to a common centre, could not be brought about by a force moving in one direction only. The explanation offered for these "Complex" indications is as follows:—"Mr. Hall accounts for them thus; he says, 'I think every sign, as far as I can judge on that ground, between the shaft and the separation doors, shows *that the blast passed over the ground twice*, and I have no doubt but what it did,' meaning that the force proceeding from Grover's side, went through the Return, and thence back again into the Cilfynydd Level, producing these indications of force outwards from the point B; and the other Inspectors agree with this explanation."[5] The indications outwards from the point B, are from the Cilfynydd Stables to the Shaft (Plate II.).

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[1] "Reports on the Disaster at the Albion Colliery," p. 16.

[2] Ibid., p. 16. [3] Ibid., p. 16. [4] Ibid., p. 17. [5] Ibid., p. 19.

This explanation demands the hypothesis that the "Blast" in Grover's Level divided, one portion escaping up the Downcast Shaft, the other rushing into the Boiler Gallery, disrupting the brick partitions and iron doors; then turning a right angle in the Return, dividing again at the Upcast, one portion escaping up the Shaft, the other rushing along the Return, and turning another similar angle into Cilfynydd Boiler Gallery, disrupting the brick partitions and iron doors there, and on reaching the Cilfynydd Level turning a fourth angle, causing further disruptive effects to the Downcast Shaft. It is impossible to conceive that a gaseous body rushing round four right angles, and splitting up at the intermediate shafts, could effect disruptive violence on each side of the square. The violent effects at the two engine houses, and in both boiler galleries, demand local and immediately adjacent explosions for their explanation.

The suggestion that the blast passed over the ground twice, is also difficult to understand as an explanation of opposing evidences of the direction of disruptive forces. The forces generated in a gaseous explosion propel the air in all directions, and are immediately expended in the passage of the mine, but are followed by an inrush of air back into the *locus* of the disturbance. There is no comparison between the forces in the explosive ignition, and the forces in the returning air; the former are of shattering violence, the latter exert no violence. The displacement and fracture of timber, brick walls, and iron doors, cannot find an explanation in the rush of air returning to an explosive centre. The explosion necessarily exhausts either the explosive gas or the atmospheric oxygen, and there cannot be a second explosion in the same *locus* in the time and circumstances under notice. The hypothesis therefore of "The blast passing over the ground twice" cannot be sustained as a solution of the opposing exhibitions of disruptive forces.

The exhibitions of force being natural phenomena, they can present no complexity if their origin be understood. Obviously the cause must be sought from the effect produced, and the evidences must be studied for what they represent. It will be sufficient for this inquiry to consider the recorded directions of force at a few points in the Levels under notice.

It is reported that "Between Dudson's Heading and the Horse Pump Dip, the indications point to the blast going in both directions, inwards and outwards."[1] The materials were displaced in contrary directions, and the cause of such a phenomenon must be the development of force at their point of divergence, and its expenditure in opposite directions, inwards and outwards, consistently with the positions in which the materials were found displaced.

The Boiler Gallery for the Grover Engine was at right angles with the Level; and the engine was lying upon four beams under the roof adjacent to the junction of the Gallery and Level. The beam nearest the Gallery was displaced, the others were undisturbed. The brick partitions and iron doors in the Gallery were broken down and hurled away into the Return. These effects show that a force was generated in the Level opposite the Boiler Gallery, and expended inwards, lifting the first beam of the Engine Stage, also laterally into the Gallery, producing the disruption there. There is no record of disruption outwards towards the Shaft, but, inasmuch as the directions of force are seen into the Gallery and inward into the Level, there must have been a force outwards, in the nature of the case of the explosion of a gaseous body.

At the Cilfynydd Engine on the opposite side of the Shaft, a signal knocker, a plank, and two pulleys were displaced outwards towards the Shaft, and an adjacent pulley, and iron strap were driven away in the opposite direction. This dislodgment of strong iron and wood structures, and displacement of their parts in contrary directions, indicate the origination of force between these portions of the structure, and its immediate expenditure in the Level, inwards and outwards.

A train of twelve or fifteen trams in the siding at the Shaft on the Cilfynydd side was broken in two parts—one portion was projected outwards to the Shaft, the other inwards into the Level, showing a development of force at their dividing line, which was expended in effecting their detachment, and propelling the two parts in opposite directions.

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[1] "Reports on the Disaster at the Albion Colliery," p. 16

The last three disturbances were within forty yards of the Downcast Shaft, and all four disruptions are of the same character, showing distinct exhibitions of explosive force, and separate local explosions at the respective points. Upon this hypothesis the directions of force present no conflict, but are effects, which have their cause in isolated explosive ignitions. It is manifest, therefore, that the origin of the disaster cannot be discovered upon the evidences of directions of force, and that it would be working in a circle to pursue the enquiry in that direction. There are other evidences that disclose the nature of the disaster, and their consideration will assist the solution of the question of the relative positions of gas and coal-dust, and throw some light upon the origin.

The disruptions that were found distributed over the field of the disaster, were not only isolated and local, but their effects were characteristic. In addition to falls of roof and shattered doors, some of the miners were mutilated. About 290 men were found scattered through some 9000 yards of road, all of whom had suffered from the effects of the disaster, but some were terribly mutilated, while others bore absolutely no marks of violence. This contrast in the condition of the bodies, is more remarkable when it is remembered, that the roads in the mine are literally small tunnels, all emanating from the Shafts, and forming practically a common plane, over which the miners were distributed; and the explosion must necessarily have produced corresponding effects upon all the bodies alike, upon the hypothesis that there was a continuous blast. It was found that 275 men had suffered no disfigurement, and had died from burns and after-damp, but the remaining fifteen men were burnt and mutilated. The condition of these unfortunate men, and the places in which they met their death, is of importance, and it is therefore necessary to quote the records.

In Llanfabon Dip (Grover's side) a body was discovered, dismembered—the "Head was twenty to twenty-five yards further down the Dip, and three or four yards from his body; his leg was found literally torn off from above the knee."[1]

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[1] "Reports on the Disaster at the Albion Colliery," p. 7.

Some distance beyond, at Askett's Heading, "Six men were found very much battered, and an arm was afterwards found there." Near this place and "In John Morris' Dip, the body of a man, fearfully disfigured and burnt so that he could not be recognized, was found; his leg was missing."[1]

In Grover's Level, at its junction with Dudson's Heading, there were two men who "Had received very great injuries, the former having both arms broken, and the latter having received violent blows on the head."[2]

In Dudson's Heading, at its junction with Sergeant's Heading, "The body . . . was discovered with limbs torn off so that he could not be identified until his clothes were recognized by his relatives."[3]

On the opposite side of the Downcast Shaft, and in the Bodwenarth Incline, at its junction with David Rees' Heading, "The body of a man lay, with head and foot knocked off."[4]

In the Cilfynydd Level, at the junction with William Rees' Heading, "Were three bodies too much torn and injured to be recognized."[5]

These six *loci* of mutilations were in the same plane, and widely separated from each other, some being more than one-and-a-half-miles apart; but in the passages between them and beyond towards the coal faces, the 275 undisfigured bodies were found distributed.

The suggestion of a continuous blast which increased in intensity as it proceeded (see the Official Reports, pages 6 and 7), requires for its justification that violent mechanical effects should have been continuous, and that the mutilation of the bodies should have increased in the path of the blast. The violent effects of the explosion were not found to be continuous, but to occur at intervals; neither were they found to vary in intensity in the way suggested.

The condition of the bodies, and the terrible contrasts that have been recorded, must dispose of the idea of a continuous "Blast"; as they amount to demonstration that the energies which brought about

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[1] "Reports on the Disaster at the Albion Colliery," p. 7.

[2] Ibid., p. 8. [3] Ibid., p. 7. [4] Ibid., p. 7. [5] Ibid., p. 7.

the disaster, developed explosive violence with local effects upon fifteen men at numerous points over the field of disturbance, but in the intervening spaces, they had no disruptive power. These activities when traversing ordinary roads, where the 275 men were engaged, produced no disruptive effect, but when passing through large sectional areas as at junctions, where the fifteen men happened to be at the moment, shattering explosions occurred, leaving their evidences in mutilated bodies, displacements of materials, and falls of roof. These energies exhibit distinct modes of activity. At some points men and workings are torn to pieces, at others a quiet death by suffocation is all that is to be observed.

Further, two distinct explosions were heard by one of the survivors in the mine,[1] and by several observers at the surface, with a rush of dust and smoke from the Downcast and Upcast Shafts,[2] fixing two separate explosions at the bottom of these Shafts. These explosions with an interval of time and space between them, are the final evidence of fact that was wanted to complete the demonstration, that there were numerous and separate explosions throughout the field of disaster.

The theory advanced in the investigation of the Camerton Colliery Explosion, that the rationale of a disaster caused by the gases evolved from coal-dust, presents the phenomenon of intermittent explosions,[3] is now seen to have been placed absolutely beyond question, as an account of what must occur, by the evidences which were observed in the calamity under notice.

Fire-damp was a normal exhalation in the workings, and small coal or coal-dust was everywhere present; and to suppose that the intermittent explosions were caused by the former, demands the assumption that there were accumulations of gas and air in explosive proportions, ready for ignition, at each *locus* of violence. These *loci* were at or near junctions and sidings, where large volumes of air were sweeping through, and in these circumstances such accumulations could have had no existence.

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[1] "Reports on the Disaster at the Albion Colliery," p. 34.

[2] Ibid., p. 33.

[3] "Coal-Dust an Explosive Agent," pp. 17, 67, 68, and 94.

At the bottom of the Downcast Shaft the pure air which a minute previously had left the surface, was passing in a volume of 240,000 cubic feet per minute.

At the Upcast Shaft the entire volume of air from the workings passed on its way to the surface. This air had been examined some time before the disaster by one of the Inspectors, and he found that it contained insufficient fire-damp to be recognized by an ordinary safety lamp. The Return air was tested by Professor H. B. Dixon after the calamity, and he reported that the current from Grover's and Dudson's Levels showed 1¼ per cent. of fire-damp,[1] but that was only one portion of the Return air. Although about five times that per centage of fire-damp is necessary to produce a slight explosion, it has been shown by Mr. W. Galloway that air containing only ·892 per cent. of its volume of this gas is capable of forming an inflammable mixture with coal-dust.[2] Had the dust-laden air in the Upcast Shaft, measuring about 460,000 cubic feet, contained 1¼ per cent. of fire-damp, that mixture must, according to Mr. Galloway's experiments, have been ignited, and have rushed out of the Shaft with an immense volume of flame. There were many observers of the smoke and dust-laden air that issued from the Shafts, who record that they saw a dark column of smoke and dust rise out of the Upcast Shaft to a considerable height, and spread over the winding wheels of the framing, and another cloud out of the Downcast Shaft. The colour and condition of the clouds of effluent gases were favourable for the detection of flame, and they were rich in fuel to sustain a flame had it been produced in the explosions at the bottom of the Shafts; but no flame was seen.[3] It is therefore a fact in evidence that there could have been no fire-damp in the air in the Upcast or Downcast Shafts, to produce any appreciable effect even with coal-dust in suspension, at the time of the disaster: consequently fire-damp could not have been present in the explosions near the bottom of the Shafts.

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[1] "Albion Colliery Explosion Report," p. 2.

[2] "Transactions Royal Society," vol. xxiv., p. 361.

[3] "Reports on the Disaster at the Albion Colliery," p. 18.

The immense volume of air that descended the Downcast Shaft, and circulated through the workings in which the explosions occurred, therefore did not contain an appreciable quantity of fire-damp, on arriving at the Upcast Shaft; consequently there was no fire-damp in the air currents to produce the explosions that were found to have occurred throughout the field of the disaster; therefore these disturbances, like those at the Shafts, were brought about by the ignition of another gas, the only source of which was the coal-dust, distributed upon the floor and walls of the workings.

The following analysis of the coal by Mr. Edward Riley, F.C.S., is given on page 28 of the Reports upon the disaster:—

Carbon - - -	89·84
Hydrogen - - -	5·16
Nitrogen - - -	·46
Oxygen - - -	2·65
Sulphur - - -	·51
Ash - - -	1·38
	100·00

Sample dried at 212° Fah.:—

Volatile Matter - -	15·19
Coke - - -	84·81
	100·00

This volatile matter may be treated as explosive gases in the conditions, and at the temperature of the chemical actions in the mine.

In the coal faces at the extremities of the workings, on both sides of the Shaft, considerable quantities of coked residues of coal were found upon the timber,[1] affording direct evidence that the coal had been subjected to distillation, and had yielded explosive gases.

These extensive deposits of coked coal in the remote ends of all the workings, excepting Pant Dhu Dip, indicate that distillation was in active progress at these extreme points; but they formed the

[1] "Reports on the Disaster at the Albion Colliery," p. 35.

terminations of the processes which were admittedly originated in the neighbourhood of the Downcast Shaft. The origin and terminations of the distillatory actions being known, their continuity from the point of inception to their visible completions, is a conclusion that obviously arises ; and the intervening spaces afforded abundant evidence of the activities. Distillation of coal-dust must therefore have been continuous, from the origin of the disaster to the deposits of coked residues in the remote ends of the mine. The explosive gases are consequently traced to their source in the small coal ; and the intermittent explosions that characterized the disaster, have their rationale explained in the fact, that the antecedent lengths of road which betrayed no indication of mechanical energy, were gas-generating spaces, in which the gas was produced for the succeeding explosions.

The nature and extent of the distillation is disclosed in the coked residues which were found adhering to the vertical props in concrete masses, in the coked residues upon the blocks of coal in the trams, and in the immense volumes of smoke, or carbon laden gases, that issued from the shafts into the open atmosphere.

The initial explosions of the gas evolved from the coal-dust, no less than the subsequent explosions throughout the field of the disaster, demanded constant supplementary additions of heat to sustain the series of chemical actions, by which they were respectively brought about. The explosions are the evidence that these supplies of heat were generated, and the only way in which they could have been obtained, was by oxidations in the educts of the coal-dust. These oxidations were explained in the preceding chapter, where it was shown that gaseous hydrocarbons underwent partial combustion, the hydrogen constituent undergoing oxidation, by which large quantities of heat were continuously generated.

The effect of this oxidation was the separation of the carbon constituent in solid form ; and at the exalted temperature that would now exist in the educts, the remaining hydrocarbons would be dissociated, yielding free hydrogen for the gaseous explosion, and disseminating further quantities of the unchanged carbon into the atmosphere, producing the condition of smoke observed in the effluent gases at the Shafts.

The terminations of the disaster are characterized by coked residues on the timber at the remote ends of the workings, and the distillation of the faces of solid blocks of coal on loaded trams some height above the floor, showing that coal-dust was undergoing distillation, and that the trams were enveloped in gases at an exalted temperature; but there were no explosions at these points; the trams and their contents, as well as the timber and roof, were undisturbed. The identity of these phenomena with those observed at the end of Parfitt's Level in Timsbury Colliery, and the result of their investigation, will be readily recalled: and it will be seen that in the Albion disaster also, there was gas, and ignition temperature in the extremities of the workings, but no atmospheric oxygen was present to complete the explosive cycle. The termination in Pant Dhu Dip was the only exception, and that was brought about by a wet length of road.

Returning to the question of the origin of the disaster, it will be within recollection that the directions of force offer no assistance in its discovery, and therefore may be excluded from this enquiry. The remaining evidence of origin in the Cilfynydd Level, is the fall of roof. It is suggested that the fall was caused by a volume of fire-damp concealed in the strata of the roof under great pressure, which, when liberated, was ignited at the open Comet lights, and caused the explosion. If fire-damp was present, as suggested, and could, in the circumstances of its liberation, and with the volume of air passing through the Level, have been brought into an explosive condition, or ignited at a Comet light, there would be an adequate cause for the origin of the disaster, in the heat thus generated. The possibility of such an occurrence, will be seen in an examination of the conditions that prevailed.

The Cilfynydd Level was in solid coal for 137 yards from the Downcast Shaft (that being the length of the Shaft Pillar in this direction), and from this point all the coal was taken out, and old workings or goaf commenced. The fall measured nineteen yards in the pillar, and thirteen yards in the goaf. This part of the Level had been driven for several years, during which time the stored gas must, upon the contention that the disaster originated there, have been present in the roof. Its maximum tension to burst down the roof, would be when

the Level was first driven ; as the extraction of the coal must necessarily have been followed by subsidence of the roof of the Level on the fringe of the pillar, and in the goaf upon either side, effecting relaxation of that tension, if not release of the imprisoned gases. It is difficult to understand that gas could have remained at any tension in the strata, within nine feet of the roof of the Level, after the coal was worked out beyond the pillar ; and it is almost inconceivable that it could have continued stored there for several years, with a large extent of long wall working partly under it and immediately adjacent, and then suddenly burst down the roof without any appreciable alteration in the conditions, or warning by indications of pressure.

At the time of this suggested gaseous outburst, 118,754 cubic feet of air were passing through the Level at a velocity of about 1300 feet per minute. Seven or eight Comet lamps were suspended from the roof, between the Downcast Shaft and the Lamp Station at Pant Dhu Dip, a distance of about 200 yards. The seventh Comet from the Shaft would be under the fall, and the sixth and eighth several yards from either end. A gaseous body, at a tension adequate to burst down thirty-two yards of the roof of the Level (more than one half in solid coal), to a height of nine feet in the middle, tapering out irregularly to nothing at the ends, must have caused a great disturbance : in which the Comets suspended from the roof could scarcely have escaped extinction before the fire-damp had been exposed to the lights sufficiently, to effect its ignition.

The Cilfynydd Boiler Gallery was situated between this supposed violent outburst of fire-damp, and the Downcast Shaft, and it disclosed explosive violence on the Return side ; the iron doors and brick-work being driven towards the In-take or Cilfynydd Level, in the opposite direction to what must have resulted from the supposed gaseous explosion under consideration.

The suggested origin of the disaster at this fall, in an explosion of fire-damp, becomes untenable when confronted with the few difficulties that have been considered.

The fall of the roof requires explanation ; but as it was at the fringe of the Shaft pillar, partly in old workings, and partly in solid coal, this appears to present little difficulty. The pillar of coal was left to sustain

the Shafts and the strata immediately around them, which would have been endangered by subsidences had all the coal been taken out. The extraction of the coal from the boundary of the pillar inwards, was necessarily followed by a sinking down of the roof; and the edge of the pillar formed a fulcrum, upon which the strata was bent over and down into the goaves, on either side of the Level, causing an internal dissection in the rock in its planes and joints, which inevitably extended back over the pillar of coal. In the ordinary course of mining, the roof at this fall must have been in a favourable condition for dislocation. The highest point in the fall was at the fulcrum formed by the edge of the pillar, which was the centre of the internal disintegration of the strata. In the investigations of the explosion at the Camerton Colliery[1] it will be found that strong stone roof was broken down, and falls produced by the local explosions there, of much greater magnitude than the fall under consideration; and these were caused by the explosive ignitions of gas obtained from the coal-dust. In the explosive ignition of gas obtained from a corresponding source, between the Downcast Shaft and the centre of the fall, this disruption of the roof has an adequate explanation.

The suggested origin of the disaster in Grover's Level, was founded upon the evidence, that timber frames of upright posts and transverse bearers, at a place about forty yards inside of the Horse Pump Dip, had to be removed, at the time it occurred; and this operation was to be performed by exploding charges of Gelatine Dynamite in holes bored in the feet of the posts, and in the bearers. It was stated in the evidence that the bodies of three men were found in the vicinity, whose only business there, was to prepare the charges of Gelatine Dynamite, make the usual examination for gas and dust before shot-firing, and to fire the shots. The work was done, and the timber frames were found broken down in the Level, mingled with about eight trams of broken strata.

The operation of removing frames of timber by explosives, was performed by boring holes in the middle of the bearer near the roof, and in the upright posts, from a few inches to two feet above the floor of the Level: and charging each one with from two to two-and

[1] "Coal-Dust an Explosive Agent," pp. 20–26.

a-half ounces of Gelatine Dynamite;[1] consequently there would be three such charges in each frame.

Assuming that the three explosive charges in one frame only, were fired, and that the medium quantity of two-and-a-quarter ounces was employed in each hole, the total heat generated would be represented by 336,948 units, the unit being the heat required to raise one gramme of water from 0°C to 1°C. The quantity of heat energy expended in displacing the timber, could be but a fraction of this total; as the uprights needed only a small displacement from the vertical to bring about the collapse of the frame. If one quarter of the energy be demanded for the work done, there would then remain over 250,000 units available for chemical actions in the small coal and coal-dust in the Level.

It was proved in the Camerton Colliery investigation, that less than 140,000 gramme units of heat originated the disaster there: and in a preceding page of this volume, it has been shown that practically the same quantity of heat produced the explosion at the Timsbury Colliery; but the surplus heat in the charges of explosive in one frame of the timber in Grover's Level, exceeded this quantity by over 75 per cent., and two out of the three charges were in the most favourable positions near the floor, to act immediately upon the coal there. It is more than probable that the charges of explosive in the second frame of timber, were also ignited in the conditions that arose immediately after the charges in the first frame were fired. It is therefore obvious that there was adequate heat to originate the distillatory action in the coal, allowing for the increased demand for the distillation of the larger quantity of coal required to yield equal volumes of educts, due to the different percentages of their volatile matters; and there is no necessity to call into requisition any supposed accumulation of fire-damp in the small cavity in the roof near the timber.

It is recorded that "The largest amount of charring was observed upon some collars,"[2] in the immediate vicinity of this shot-firing,

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[1] "Reports on the Disaster at the Albion Colliery," p. 8.

[2] Ibid., p. 35.

showing that there was a large generation of heat here, and that a considerable quantity was free in the passage for chemical activities.

Where small coal is the source of the explosive gas, a length of road must intervene between the origin of the distillatory action and the explosive ignition, in which the explosive gas has to be generated. It was observed in this disaster, that for ninety yards inside, and for the same distance outside of the timber that was to be removed by shot-firing, nothing was disturbed, though the Level was closely timbered and lagged.[1] A passage that required to be timbered to this extent, could offer no effective resistance to the disruptive forces of an explosion: but would inevitably collapse. The condition of this 180 yards of undisturbed timber, is direct evidence that there was no explosion there: and as it was situated in the heart of the field of disaster, there can be no question that it was a gas-generating space. The hypothesis that the disaster originated in this undisturbed length of timbering, has this evidence in its favour, that coal-dust was undergoing distillation there, and consequently explosive gases were produced and flowed into the atmosphere of the passage; that gaseous explosions occurred at both ends of the timbering, and were repeated at intervals in both directions, to the extremities of the mine.

The evidences in support of the origin of the disaster in the Cilfynydd and Grover Levels respectively, have now been considered; and as the expert witnesses limit the inception to these two points, there can be no difficulty in recognizing the superior grounds for the conclusion, that the disaster was originated near the Horse Pump Dip, in Grover's Level.

The foregoing examination of the records of the Albion Colliery disaster, discloses an important correspondence of its phenomena, with the phenomena of the explosions at the Camerton and Timsbury Collieries. Each disaster is characterized by an undisturbed length of road at its origin, in which heat was suddenly generated, that set up distillation in the coal-dust, and a series of chemical actions which closed in the initial gaseous explosions. Their respective developments from these initial explosions, equally disclose immediately succeeding undisturbed lengths of road, in which the chemical actions were renewed and closed in

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[1] "Reports on the Disaster at the Albion Colliery," p. 36.

second explosions; which were followed by repetitions of the same processes again and again through the mines, so that each field of disaster presented corresponding phenomena, of numerous gas generating spaces, ending in exhibitions of explosive violence. The terminations of their phenomena alike show that their chemical actions were arrested by wet spaces, or inadequate supplies of atmospheric oxygen. All the explosions occurred in large sectional areas of road, where increased supplies of oxygen were obtainable. In each mine the available oxygen for the chemical activities was limited (at the Albion and Timsbury Collieries the supplies of air were suspended), and at the ends of the workings it was exhausted, so that no explosive ignitions could be effected there. The educts from the coal-dust underwent partial combustion with constant generation of heat, and an elevation of temperature adequate to effect destructive distillation at the faces of blocks of coal on loaded trams; resulting in the separation of the carbon constituent of the gaseous hydrocarbons in solid form, which was not oxidized, but issued from the shafts in the gaseous products of the explosions, giving them the character of smoke.

These three explosions in gaseous and non-gaseous mines, are therefore found to present phenomena that are identical in character, which demand for their explanation a corresponding origin and rationale. A conclusion of such moment, necessitates a further examination of the phenomena of explosions in other gaseous mines.

An explosion occurred at the Malago Vale Colliery, Bristol, on August 31st, 1891, in which ten men were lost, and the Coroner's Jury returned the verdict that it was "Caused by an explosion of gas, the said gas having been liberated by a fall of the roof and fired by contact with a naked light, carried by a workman, contrary to the regulations of the mine." Two men were engaged at the place where the disaster originated; and when the Rescue party reached this point two or three hours subsequently, they found one of these men burnt, but alive and conscious, and able to inform them that some fire-damp had been ignited in that neighbourhood by his colleague, whom they discovered thirty yards further on, at the spot where he lighted the gas, and where he was lying burned to death. Previous to the discovery of these two men, the

remaining eight victims had been found between the origin of the explosion and the Upcast Shaft, six of them had succumbed to the poisonous after-damp, and two to violent injuries received at the bottom of the Upcast Shaft; while three other men who had been rendered unconscious by the after-damp while trying to escape to the Shaft, were rescued. It will be observed that the after-damp produced by the ignition of the fire-damp at the origin of the explosion, did not possess the poisonous properties of the after-damp that filled the workings where the other unfortunate men were found. In the former a man was found alive and conscious, but in the latter men were previously found, unconscious or dead. It should also be noted that the men at the origin of the explosion were not disfigured, but two men at the shaft a long distance away, were mutilated.

A significant feature of the after-damp was that it supported combustion. One of the survivors (the night Bailiff) stated in evidence, that after the explosion, while he was enveloped in after-damp, his lamp retained its light, and was burning when he became unconscious.[1] The Rescue party after several efforts, penetrated the atmosphere of after-damp, and found the night Bailiff unconscious, his safety lamp in his hand, still burning,[2] though it was in the Main Return Airway, and had been exposed to the entire gaseous products of the explosion for nearly two hours. The lamps of the Rescue party also burned freely in the after-damp, and afforded no indication of its dangerous properties; the only way in which it could be recognized, was by the physiological sensations it produced, and the sudden collapse into unconsciousness experienced by members of the party.

The origin of the explosion is fixed by the position of the deceased man, who was burned to death by the fire-damp ignited at his open lamp. About twenty yards away, a fall of roof was found, which was supposed to have occurred before the disaster, and to have yielded the fire-damp; but, with this exception, there was no disturbance here or anywhere in the vicinity. The two men had not been subjected to any explosive violence, as they had suffered no mutilation, and the timber

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[1] "Reports on the Explosion at the Malago Vale Colliery," p. 16.

[2] Ibid., p. 13.

and materials in the roads had not been disturbed; therefore the fire-damp was not exploded here, but was burned inexplosively, before an explosive mixture was formed.

The Upcast Shaft was distant from the origin of the explosion about 1000 yards by incline, and 220 yards more by a level Branch. There were several exhibitions of violence at separate points in the Incline: and in the junction at its upper end there was a violent disturbance, producing a heavy fall, and shattering four separation doors which barred the entrance to the Main In-take Airway.[1] The disruption here, as in the preceding disturbances, was local, and in a limited area. About 200 yards beyond, another violent explosion occurred, near the bottom of the Upcast Shaft. The cages in the shaft were kept in position by suspended iron wire rope guides $1\frac{1}{4}$ inch in diameter. Two of these guides were broken, trams were hurled across the shaft and crumpled, the roof of the level was broken down, and two men working there were mutilated and instantaneously killed.[2]

The fire-damp at the origin of this disaster, when ignited by the open light, was necessarily wholly burned at its *locus* in the passage, as there was a large current of air passing; and the only agent that remained for the development of explosive phenomena beyond, was the heat generated in its combustion; and the only source of explosive gas, was the coal-dust everywhere present. Consequently the first gaseous explosion must have been caused by gas evolved from the coal-dust; and the subsequent explosions in the Incline, and at the Upcast Shaft, were also necessarily due to gas obtained from the coal-dust distributed along the road. This conclusion is placed beyond doubt by the facts, that the timber props in the vicinity of the place where the deceased man who ignited the fire-damp was lying, were coated with residues of coked coal-dust; and more timber props ninety yards distant, were also covered with coked residues. The heat generated in the combustion of the fire-damp, therefore instituted distillatory action in the coal-dust at the origin of the disaster, and distillation was still in progress ninety

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[1] "Reports on an Explosion at the Malago Vale Colliery," pp. 8, 9, 13.

[2] Ibid., pp. 8, 9.

yards away. It is difficult to conceive that the heat generated in the volume of fire-damp, that may be reasonably supposed to have been present here, could have satisfied the demands to sustain the distillatory action for ninety yards. If the investigations in the last chapter into the extent of these demands be recalled, it will be seen that they could not be met with the heat due to the ignition of this fire-damp; and that the partial oxidation in the educts that occurred at other mines, was also necessary here, to sustain the distillation over the distance observed. This partial oxidation must have commenced where the distillation originated; therefore the series of chemical actions in coal-dust, that bring about a gaseous explosion, must have been instituted where the fire-damp was ignited, and have closed in the first gaseous explosion at the Incline; and propagation to the Upcast Shaft would follow in natural course.

This disaster was therefore originated by the heat generated in the inexplosive combustion of fire-damp, setting up chemical actions in the coal-dust, in the same way that the heat generated in the combustion of solid explosives, originated corresponding activities in the coal-dust at the Camerton, Albion, and Timsbury Collieries.

Another explosion occurred at this Colliery on March 15th last, the origin of which was traced to the firing of a shot about 300 yards from the seat of the previous disaster. The shot hole was bored at an almost vertical declivity in the bed of underclay lying beneath the coal, and charged with thirteen ounces of mining powder,[1] the object being to displace this underclay to a depth of twenty inches. The ground was only broken for a portion of this depth, and the lower part of the hole was not fractured. A considerable portion of the heat was therefore unexpended, and became available for other purposes. This shot was fired by an official, whose first duty it was to examine the place to see if it was free from fire-damp; and if coal-dust was present, to water it before igniting the charge. This official and a boy who accompanied him, sheltered themselves in a refuge hole twenty-two yards from the shot, where they were found, both were dead and severely burned.

[1] "Report on the Explosion at the Malago Vale Colliery," 1895, p. 4.

An explosion followed the ignition of the charge, but the disaster is reported, not to have been propagated to any considerable extent. An immense volume of after-damp filled the workings in the direction in which the air-current was travelling, and rendered eleven other men unconscious at considerable distances away from the shot: they were, however, all rescued, the night Bailiff referred to in the previous explosion being amongst the number. He had again fallen upon his lighted lamp in an unconscious state, and it was burning his side when the Rescue party reached him. The Rescue party pressed on into the workings for the purpose of saving the lives of their comrades, their lamps burning brightly, and giving no indication of any dangerous properties in the after-damp; but they were suddenly rendered unconscious, and some of them had to be carried back into the fresh air, to be restored to consciousness.

Fire-damp had not been seen previously in the district where the shot was fired; but after the disaster some faint traces were discovered, quite inadequate to account for the damage done in the workings. The volume of after-damp that filled the roads and vitiated the ventilation to the Upcast Shaft over one mile distant, appeared to be inexplicable: as it is beyond question that there was no accumulation of fire-damp at the shot nor in its vicinity when the charge was fired, or the official would have discovered it; and it is equally certain that there was no body of gas in the field of the disaster.

The workings are reported to have been dry and dusty, and in the coal-dust everywhere present, there was a source of gas commensurate with the effects of the explosion, and the large quantity of after-damp that was produced. The observations that are recorded of this disaster are, however, quite inadequate to enquire into its inception and development; but there is the important fact that the after-damp produced physiological effects upon the survivors and the Rescue parties, identical with those experienced in the after-damp in the preceding explosion; and on both occasions the lamps burned brightly, giving no indication of its deadly properties. The gaseous bodies, the products of the oxidations of which caused the same effects, must themselves have been identical in composition; and as the gaseous bodies in the preceding disaster have

been shown to have been obtained from the coal-dust by distillation, so must these bodies in the last explosion have been produced from a corresponding source.

These physiological sensations and burning lights in the after-damp, correspond with the experience in the products of the oxidations in the explosions at the Camerton and Timsbury Collieries, and demand the conclusion, that identical gases were oxidized in the four disasters in the three mines, in two of which fire-damp was unknown.

These two disasters in the Malago Vale Colliery, one originated by the heat generated in the ignited fire-damp, the other by the heat produced in the combustion of a solid explosive, not only provide this important identity in the gases exploded in gaseous and non-gaseous mines, but the recorded features of the first disaster show also a correspondence in their inception and rationale; as it will be remembered that there was an undisturbed space at the origin, in which distillatory action was instituted, that heat was generated in the educts, and that the subsequent development was by local explosions at intervals of time and space, identical with the observed facts in the non-gaseous mines.

In February, 1890, an explosion occurred at the Llanerch Colliery, Monmouthshire, in which 176 lives were lost. Mr. J. S. Martin, H.M.'s Inspector of Mines, stated in his Report (1890), page 15, "There was no indication in any part of the workings that any shot had been recently fired, and the explosion is distinctly in no way connected with such operations;" and further, on page 16, "There practically was unanimity at the inquest in fixing the point of ignition at the Horse Windway of No. 4 Level. Also that there was an ignition of fire-damp at a naked light used there by the men who were repairing. . . . There appear to be no grounds for thinking that there were any known accumulations of gas in the mine that morning." At this point of No. 4 Level there was a cavity in the roof, which contained a little fire-damp, and there was an upheaval of the floor, which also yielded gas. The explosion therefore had its origin in the heat generated in the ignition of fire-damp.

The recorded observations of the phenomena of this explosion are inadequate for an enquiry into its development; but it is important to remark that the timber in the three roads immediately adjacent to the

cavity were not disturbed, and a ventilating sheet there was not displaced, but the timber was "Charred," and showed "Signs of Burning."[1] Mr. Martin, in his Report already referred to, speaks, on page 15, of "Timbers thickly coated with dust, or charred dust;" therefore the expression "Charred," descriptive of the condition of the timber in the neighbourhood of the cavity, evidently means that they were coated with coal-dust that had been subjected to heat. The origin of the explosion is consequently characterized by an absence of explosive violence, and by distillatory action in the coal-dust; showing that there was an inexplosive ignition of fire-damp: in the combustion of which, a sufficient quantity of heat was generated to initiate chemical activities that are known to develop disaster. The processes that followed the distillatory action at the cavity, cannot be worked out in the absence of detailed observations of the effects in the mine; but the noise heard at the top of the Upcast Shaft, and described as that of a cannon shot, and the "Body of black smoke" that rushed out of the shaft about half-a-mile from the origin of the disaster, with the fact that the lights of the Rescue parties burned in the after-damp, leave no room to doubt the nature of the development, or the chemical actions necessary to its production.

The record that there were "Heavy falls at the entrances of No. 4 and No. 1 Headings,"[2] over 500 yards apart; and "Minor falls in different parts;"[3] and the fact that the bodies of the miners at various points in the workings were mutilated, while the bodies in the intermediate spaces and beyond them, had suffered no violence, death by burns or suffocation being all that could be observed, show that the field of the disaster was characterized by numerous local explosions.

The phenomena of the Llanerch Colliery calamity therefore corresponds with the phenomena of the Malago Vale Explosion, 1891, and provides additional evidence of the identity of phenomena in the inception and rationale of explosions in gaseous and non-gaseous mines.

Four explosions in gaseous mines, including two great catastrophies, causing the death of 466 men, have now been considered, and found to

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[1] "Report on the Llanerch Colliery Explosion," p. 9.

[2] Ibid., p. 10. [3] Ibid., p. 10

be identical in character with the disasters in non-gaseous mines. The question may now be raised as to the nature of the explosions in gaseous mines, and wherein they differ from explosions in non-gaseous mines, and the Author proposes in the first place, to inquire into the products of the oxidations of gases in the explosions.

It will be remembered that in the non-gaseous mines, the elementary and therefore invariable substance hydrogen, was produced and exploded.

The fire-damp which is supposed to have caused the explosions in gaseous mines is variable in its composition, as will be seen by the following analyses[1] :—

	Wallsend.	Hebburn.	Gateshead.
	PLAYFAIR.		GRAHAM.
(Methane) Carburreted Hydrogen	77·5	91·8	94·2
Nitrogen	21·1	6·7	4·5
Oxygen -	—	·9	1·3
Carbonic Acid - -	1·3	·7	—
	99·9	100·1	100·0

The fire-damp which escapes into the passage of a mine at the moment before an explosion, may be represented by either of the foregoing compositions, or an intermediate one; but as only about 10 per cent. of the gas is required in admixture with air to produce the maximum explosion, the variation in the composition becomes practically unimportant.

Chemistry teaches that when a mixture of hydrogen and air is exploded, the products are water vapour and free nitrogen; but when a body of fire-damp and air is exploded, carbon dioxide, water vapour, and nitrogen constitute the atmosphere produced. Both of these atmospheres are incapable of supporting combustion, but they have this difference, the products of the fire-damp contain a considerable proportion of carbon dioxide, the most powerfully extinctive gas known: which has no place in the products of the combustion of hydrogen.

[1] "Report of the Coal-Dust Committee, Chesterfield and Derbyshire Institute," p. 42.

Therefore given these two atmospheres in equal volumes, and allowing air to flow into each one at identical rates until they are capable of sustaining the flame of a candle or lamp, it will be found that this condition of supporting combustion arises almost immediately in the products of the hydrogen explosion; but a large volume of air will be required to raise the products of the fire-damp explosion to that state, and this will necessarily occupy a considerable time.

Carbon dioxide is one of the normal exhalations of all coal mines, and its presence in their atmospheres in small quantities, is known and recognized by every one engaged there. Every experienced miner has at some period of his life recognized its presence in the air in which he was working, by the effect it produced upon his candle or lamp, though he himself had felt no appreciable physiological sensation; therefore carbon dioxide is a prevailing and easily-recognized gas in mines, and the Rescue parties that enter a mine after an explosion, are familiar with its indications, and are able at once to detect its presence.

Investigations have been made of the composition of the atmosphere which fails to sustain combustion. Dr. Lorrain Smith and Dr. John Haldane found by experimental investigation, that a match could not be ignited in air containing 17·7 per cent. of oxygen and 2·5 per cent. of carbon dioxide.[1] Subsequently Dr. Haldane communicated a Paper to the Royal Society upon the nature and physiological action of Black-damp, which is one of many terms employed in mining districts, to designate an atmosphere containing carbon dioxide. He found that the Black-damp at the Lilleshall Colliery was of the following composition :—

Oxygen - - -	17·05
Carbon Dioxide - -	2·62
Nitrogen - - -	80·33
	100·00

[1] "Journal of the Society of Pathology and Bacteriology," 1892.

and that it extinguished both the candle and the safety lamp.[1] Referring to the physiological effects of this atmosphere upon himself and his party, he remarks:—"None of us could detect any loss of power or headache or any other abnormality, nor did we trace any effect after coming out of the mine.[2] Professor Frank Clowes has also investigated the subject of extinctive atmospheres, and his interesting Papers upon the subject are in the same volume of the Proceedings of the Royal Society.

Later investigations have been made by Dr. Haldane, and Mr. W. N. Atkinson, H.M.'s Inspector of Mines, of the extinctive gases collected from workings in collieries, and they found that candles were extinguished in an atmosphere of the following composition[3]:—

	Lilleshall Colliery.
Oxygen - - -	17·64
Nitrogen - - -	80·15
Carbon Dioxide - -	2·21
	100·00

They also found that the first physiological action was experienced by breathing becoming noticeably deeper, in the following composition[4]:—

Oxygen - - -	15·30
Nitrogen - - -	81·32
Carbon Dioxide - -	3·38
	100·00

and that pronounced action was felt with severe respiratory distress, when the quantity of carbon dioxide was doubled, the constitution then being[5]:—

Oxygen - - -	9·60
Nitrogen - - -	83·08
Carbon Dioxide - -	7·32
	100·00

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[1] "Proceedings Royal Society," vol. lvii. [2] Ibid.

[3] "Transactions of the Federated Institutes of Mining Engineers," vol. viii., p. 557.

[4] Ibid. [5] Ibid.

These investigations show that air containing 2·21 per cent. of carbon dioxide, extinguishes lights; and that the first physiological sensation arises with 3·38 per cent. of that gas. Dr. Haldane and Mr. W. N. Atkinson state that they had numerous opportunities of personally observing the symptoms produced by these atmospheres, containing carbon dioxide, and always found that the first physiological effect was experienced, when the air was contaminated considerably beyond the point at which an oil lamp ceased to burn; and that a further contamination produced effects comparable with those "Caused by running." They add, "We never experienced any after effects from breathing Black-damp, even when we had been for a considerable time in an atmosphere which instantly extinguished a lamp.[1]

The foregoing investigation shows that if the gaseous products of an explosion contain 2·21 per cent. of carbon dioxide, they will not sustain a light; and that quantity must be increased over 50 per cent. to produce any physiological effect.

The effect of the products of explosions in gaseous mines, upon the lights of the Rescue parties, therefore, affords direct evidence upon the presence of small quantities of carbon dioxide; and as the lights burned brightly in the atmospheres that filled the Albion, Malago Vale, and Llanerch Collieries, it is obvious that they could not have contained 2·21 per cent. of that gas. This fact involves a conclusion of great importance, and it is therefore necessary to consider further records upon the point.

Mr. J. Dickenson, late H.M.'s Chief Inspector of Mines, who had had a large experience in explosions in gaseous mines, gave evidence upon this subject before the Royal Commission upon Accidents in Mines (1879), which will be found in the preliminary Report, as follows :—

Question 38.—"Do you, in your district, meet with any other deleterious gases besides fire-damp, any black-damp?"

"Yes; all mines, if not well ventilated, are subject to black-damp, and rarely to what we call white-damp, which is probably carbonic oxide."

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[1] "Transactions Federated Institutes," vol. viii., pp. 555, 556.

Question 39.—"Not given off from the measures?"

"Yes, sometimes, I think, but more particularly from the gunpowder, and more frequently you meet with it near a fire in the mine. It is a nasty gas to deal with, is the white-damp, because your light burns, and you can only judge of its effects upon the human frame by perhaps your legs trembling, or your head getting out of sorts, and unless you retire, you will be struck down and killed. But the black-damp nearly always gives ample warning, and unless you get suddenly into it, you generally have time to escape. The light goes out. Dr. Angus Smith, the Chemical Inspector, says, when there is about 2 per cent., and that 4 per cent. would suffocate."

Question 46.—"Is black-damp the same as choke-damp?"

"Yes, carbonic acid chiefly."

Question 47.—"Is that the same as after-damp?"

"No, that is a different thing. After-damp is the product of the combustion of fire-damp."

Question 48.—"That is a suffocating gas?"

"Yes."

Question 49.—Is it of the same character as white-damp?"

"Practically the same. In going into a mine after an explosion we go as quickly forward as we can to see if anybody is alive. The way I judge as to how far one can venture in, is principally by the effect upon the eyes and the general effect upon the system. I know of no other way of judging the quantity of after-damp which there is, but by these indications."

Question 50.—"Principally by the effect upon the eyes and upon the general system?"

"Yes, it is a slightly pungent gaseous smell which sticks to woollen clothes for days afterwards."

Question 51.—You would probably describe the effect upon the general system as a kind of *malaise* or torpor?"

"Yes."

It will be observed Mr. Dickenson points out that in an atmosphere containing 2 per cent. of carbon dioxide, the light goes out; but in

carbonic oxide, which he thought was practically of the same character as after-damp, the light burns.

When it is remembered that the workings of a mine are in total darkness, and that after an explosion they are in a very dangerous condition, and obstructed by falls of roof and timber, it will be seen that it would be impossible for Rescue parties to travel in them without lights, in searching for burnt and injured men; and as the lights burned in the after-damp, the only indications these parties could have of its presence, were the effects upon the eyes and head, and the "*malaise* or torpor" it caused.

Messrs. W. N. and J. B. Atkinson, in their volume already referred to, observe that "The after-damp encountered in the Durham Collieries after the explosions (which killed 330 men), appeared to possess very deadly properties. At Trimdon Grange, Tudhoe, and Usworth, it caused the death of persons who descended after the explosions, and in many cases the explorers suffered severely from it."[1] And again "After the Durham explosions, the lamps burned brightly, and when they gave no indication of the presence of any kind of gas, men were overpowered. The writers have been affected under such circumstances on entering parts of the pits where ventilation had not been restored, and have been present when persons lost consciousness, and had to be carried back into purer air, and yet no indications were given by the lamps. It was observed that the oil in some of the lamps of the victims who had perished from after-damp while waiting for rescue, was exhausted, as if the lamps had not been extinguished by the after-damp which killed the bearers, but had burnt until the oil was consumed."[2]

It is also recorded of the great explosion at Clifton Hall Colliery in 1885, in which 177 lives were lost, that the lamps burned in the after-damp, and the Manager of the adjoining Colliery, who was in a Rescue party, describes the sensations he experienced as follows:— "It seemed as if life was just about to go. There seemed to be

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[1] "Explosions in Coal Mines," p. 112.

[2] Ibid., p. 112.

darkness with me closing in, and they the same. You could not breathe any more than that *(describing)*, and my knees began to tremble. I felt a sort of blinding, and nature going altogether." At the same time all their lamps were burning, so that they were able to escape, back over the falls in the road.[1]

In the calamity of equal magnitude at the Llanerch Colliery in 1890, in which 176 men were killed, the lights of the Rescue parties burned brightly in the after-damp.

An explosion occurred at the gaseous Spring Hill Mines, Nova Scotia, on February 21st, 1891, and it is recorded that: "Almost immediately after the explosion men were able to go straight into the faces of the levels. Their lamps burned well, although they were themselves affected."[2]

It would be superfluous to multiply this evidence upon the fact, that lights burn in the after-damp of the explosions in gaseous mines; and adequate records have been quoted in this investigation for evidence to prove, that while after-damp permits the flame of the lamp to continue burning, it produces unconsciousness and eventually death, if its inhalation be continued sufficiently long.

It will be within recollection that when quoting analyses of the composition of fire-damp, it was observed that about 10 per cent. in admixture with air, made the maximum explosive strength; and to avoid small and unnecessary complications, it will be assumed that this quantity is practically all Methane. One volume of methane yields by its oxidation one volume of carbon dioxide, consequently carbon dioxide must form 10 per cent. of the atmosphere produced by an explosion of fire-damp.

The investigations quoted on a preceding page, show that an atmosphere containing 7·32 per cent. of carbon dioxide, produced severe respiratory distress, and 8·00 per cent. was fixed by Dr. Haldane as constituting an atmosphere fatal to breathe; but it has been found that Rescue parties have lived in after-damp for considerable periods,

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[1] "Report on the Explosion at the Clifton Hall Colliery," pp. 34, 35.

[2] "Transactions Federated Institutes of Mining Engineers," vol. viii., p. 156.

while searching for the miners, and suffered no respiratory distress as produced by running; but a gradual and silently diminishing vitality. Dr. Haldane also records that he suffered no loss of power in the carbon dioxide atmosphere, and could trace no physical effect on coming out of the mine: whereas the Rescue parties suffered complete loss of power in the after-damp, and some died after coming out of the mines.

The physiological effects produced by after-damp, are therefore different in character from those experienced in an atmosphere containing carbon dioxide; and it has been shown that if three-fourths of the quantity of carbon dioxide, that must be produced by a violent explosion of fire-damp, were present, the Rescue parties must have been seized with severe respiratory distress immediately they entered the after-damp; and in the normal product of that gas, fatal effects must have at once ensued.

The investigations also showed, that an atmosphere containing 2·21 per cent. of carbon dioxide extinguished the lights; but it has been found that lamps and candles burn freely in after-damp, therefore it does not contain one-fourth of the volume of carbon dioxide that is produced by an explosion of fire-damp that exerts the maximum violence, and any mixture that contained a less quantity of fire-damp, could not have produced the disruptive effects observed; consequently where after-damp is found, there can have been no appreciable explosive combustion of fire-damp.

The volume of fire-damp which is equivalent to the production of an atmosphere containing 2·21 per cent. of carbon dioxide, cannot be exploded: and three times that volume is required to make an explosive mixture, while over four times as much is necessary to effect an explosion of the greatest violence; but after-damp does not contain 2·21 per cent. of carbon dioxide, consequently it cannot be the product of the explosive combustion of fire-damp.

The evidences therefore prove that the after-damp that filled the workings of the mines after all the great explosions, could not be produced by the explosion of fire-damp: and though fire-damp was ignited at the origin of some of the disasters: their subsequent developments were brought about by the oxidation of another gas, which in its

ignition yielded essentially different products, in which carbon dioxide occupied no place. It is therefore beyond question that fire-damp could not have been appreciably present in the large explosions in gaseous mines; and the nature and source of the gas that caused the calamitous effects, is not far to seek, inasmuch as the products of its oxidation, produced effects identical with those observed in the Camerton and Timsbury Colliery explosions, which were brought about by the oxidation of hydrogen gas, obtained from the destructive distillation of coal-dust.

The explosions in gaseous mines have caused a loss of life, beyond any comparison with what has occurred in non-gaseous mines: but there is a correspondence in the area of the fields of disturbance in the respective mines; and remembering their magnitude, it will be expected that they should present some indications of the extensive distillation, that was essential to produce their explosive phenomena; and attention must now be turned to the mines to see what evidence they afford of this action.

It will be within recollection that residues of coked coal were observed at the Camerton and Timsbury Collieries, proving that there had been destructive distillation of coal, from which gaseous hydrocarbons flowed into the atmosphere of the mine; but that these residues became attached to opposing objects under special circumstances, and that it would be fallacious to consider these visible deposits as representing the sphere of the distilling action. The deposition of carbon was, however, universal in the fields of disturbance, and as it could have had no origin except in the gaseous hydrocarbons evolved from the coal, the distillation must have been co-extensive.

Gaseous mines present identical evidence of distillation of coal in deposits of coked residues. The late Professor Faraday and Sir Charles Lyell drew attention to these deposits, from which, they observed "Much coal-gas was made," in their Report[1] upon the Haswell Colliery Explosion in 1844. Coked residues of coal were also found after the explosions at the following Collieries, *viz.*, The Albion,[2] Alltofts,[3] Apedale,[4] Blantyre,[5]

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[1] "Philosophical Magazine," vol. xxvi., 1845. [2] "Reports on the Disaster at the Albion Colliery," p. 35. [3] "Report of Royal Commission on Explosions from Coal-Dust," Question 3723. [4] Ibid., Appendix xxi. [5] Ibid., Questions 4414-4417.

Bryn,[1] Clifton Hall,[2] Hyde,[3] Llan,[4] Llanerch,[5] Malago Vale,[6] Mardy,[7] Mossfields,[8] Penygraig,[9] Risca,[10] Trimdon Grange,[11] Udston,[12] and West Stanley Collieries.[13] There is no doubt that these deposits existed in the explosions at other Collieries, but escaped observation; as their recorded phenomena demand gases from coal-dust for their explanation.

The deposits of impalpable carbon, do not appear to have received much attention except that Mr. Galloway in his No. 1 Paper to the Royal Society, vol. xxiv., page 358, stated that he was able to descend the Llan Colliery within two-and-a-half-hours of the Explosion, and when the ventilation was only partially restored, and added, "At that time the air in all the unventilated parts of the workings near the Level in which the explosion had taken place (so far as they could be explored with safety), were so charged with *coal-smoke soot*, and other products of the imperfect combustion of coal, that it was difficult to distinguish objects two or three feet distant." In the interval of two-and-a-half hours all coal-dust thrown into the atmosphere of the mine by the explosion, must have subsided and become deposited in the passages; so that what Mr. Galloway observed floating in the air, would be a much finer, and an impalpable form of powder. Again in vol. xxviii., page 414, Mr. Galloway speaks of "Soot" as a general product of explosions; and in vol. xxxiii., page 445, he describes the edges of some of the shelves of the chamber, in which his experiments were conducted, as being "Covered with a thin deposit of soot and dust which had a velvety feeling when touched."

In the Mardy Colliery Explosion "Soot" was observed throughout the whole field of disaster.[14]

Though these deposits have been the subject of very limited observations after explosions in gaseous mines; their presence has

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[1] "Report of Royal Commission on Explosions from Coal-Dust," Question 236. [2] "Report on the Explosion at Clifton Hall Colliery," p. 13. [3] "Report on the Explosion at Hyde Colliery," p. 8. [4] "Proceedings Royal Society," vol. xxiv., p. 359. [5] "Report on the Explosion at Llanerch Colliery," p. 9. [6] "Reports on the Explosion at the Malago Vale Colliery," 1891, p. 9. [7] "Report on the Explosion at the Mardy Colliery," p. 6. [8] "Report on the Explosion at Mossfields Colliery," p. 12. [9] "Proceedings Royal Society," vol. xxxiii., p. 493. [10] "Report on the Explosion at the Risca Colliery," 1880, p. 69. [11] "Explosions in Coal Mines," p. 48. [12] "Report on the Explosion at the Udston Colliery," p. 7. [13] "Explosions in Coal Mines," p. 61. [14] "Report upon the Explosion at the Mardy Colliery," p. 6.

been recorded under the designation of "Smoke and soot," in a few cases; but if their origin and significance had been recognized, they must have formed an important element in the records of the phenomena of these disasters.

Whatever limitation, however, attaches to the records of this carbon on the walls of the workings, there is no question of its universality in the gaseous products that issued out of the Shafts into the open atmosphere, after every explosion, excepting only small and local ignitions of fire-damp, which developed no further action. In the Blantyre Colliery Explosion, "A great volume of smoke and dust came to the top" (Report, page 7). At Mardy Colliery, "A cloud of dust and smoke" ascended the Downcast Shaft (Report, page 6). At Udston Colliery, "A cloud of dust and smoke shot out of the Downcast Shaft" (Report, page 5). At Clifton Hall Colliery, "Smoke and dust issued from both pits" (Report, page 68). At the National Colliery, "Dust and Smoke" issued from the Downcast Shaft (Report, page 5). At the Albion Colliery, "A column of smoke from the Upcast Shaft" (Reports, page 18). At Llanerch Colliery, "A tremendous body of black smoke issued from the Shaft" (Report, page 9).

It is not necessary to multiply the records of this phenomenon, as the foregoing extracts indicate its character in all the explosions; its importance is in the fact that this condition of a gaseous body designated smoke, is due to suspended solid matter in a state of fine division, which is necessarily the solid or carbon constituent of gaseous hydrocarbons, that had become separated from the hydrogen: and being too fine and flocculent to gravitate to the floor, it remained in suspension in the gaseous products of the explosions, giving them the character of smoke; and corresponding with what is constantly seen issuing from the high chimneys of boiler fires at Collieries, and manufacturing works.

These carbon-laden clouds that rushed out of the shafts, and which had their origin in the explosions in the mines: disclosed in open daylight, the condition of the atmosphere in the workings below ground; therefore in the nature of the case, the atmosphere that filled the underground workings, was laden with carbon, and portions of it would be inevitably deposited upon the enclosing walls of the passages, as the gaseous products pressed against them, while passing through to the Shafts.

These deposits of carbon would therefore be co-extensive with the fields of disaster; and the limited records made of them, have an explanation in the fact, that they were not recognized as a significant element in the explosions: nor as affording any evidence for the elucidation of the chemical processes, by which the calamities were brought about.

These phenomena of coked residues and flocculent carbon, therefore provide unmistakable evidence that the distillation of coal-dust, and dissociation of the evolved gaseous hydrocarbons, were in operation throughout the fields of disturbance. These operations would result in the production of bodies of free hydrogen; and the existence of volumes of highly explosive gas throughout the ranges of disturbed workings, will therefore be readily understood; while the shattering explosions at various points, with intervals that betrayed no effects of violent forces, are natural consequences. It will now be recognized that the absence of carbon dioxide in the products of combustion, was due to the fact, that the carbon was not oxidized.

The quantity of coal-dust present in mines may be gathered from Mr. W. N. Atkinson's Report, forming Appendix viii. in the Report of the Royal Commission on Explosions from Coal-Dust. Mr. Atkinson made an examination at the Apedale Colliery, to ascertain the quantity of coal *débris* upon the floor of the road, at the origin of the explosion; and taking a length of ten yards of the passage, he found that it averaged 19·73 pounds per square foot of floor surface, 12·08 pounds of which passed through a half-inch riddle, and 2·65 pounds of this amount passed through the gauze of a safety lamp having 784 apertures per square inch. This was a case of an excessive accumulation of dust; but when it is remembered that only two ounces of coal-dust per square foot of floor surface was sufficient to yield the gas that caused the Camerton and Timsbury Explosions, it will be recognized that there is an excessive quantity prevailing in mines, beyond the demands for the explosive phenomena under notice.

The source and nature of the explosive gas, by which the explosions are produced, being found to be identical in gaseous and non-gaseous mines, this enquiry may now be directed into their rationale.

Where the points of origin of the disasters have been localized, it

has been observed that the roads in their vicinity presented no indications of explosive violence; the timber was undisturbed, movable materials were not displaced or damaged, and when miners were near the points, they were not mutilated. These lengths of undisturbed passage measured respectively, 100 yards at Seaham Colliery,[1] 140 yards at Tudhoe Colliery,[2] 150 yards at Usworth Colliery,[3] 140 yards at Elemore Colliery,[4] 160 yards at Alltoft's Colliery,[5] and 180 yards at Albion Colliery;[6] and at each place there were evidences that shots had been fired. The first disruption at the Malago Vale Colliery is not recorded; but from the plans accompanying the Reports, it is evident that there was no explosive violence within sixty yards of the point where the fire-damp was ignited, and it was stated in evidence that there was no disturbance between this point and the Incline, which was fifty to sixty yards distant.[7]

Messrs. W. N. and J. B. Atkinson drew attention to these undisturbed spaces in the Durham disasters, and suggested that they marked the origin of the "Dust Clouds," to which they attributed the developed explosions; their significance, however, is in the evidence of fact, that there were no explosions of fire-damp at the origin of the disasters, but that series of chemical actions were instituted, which yielded constant supplies of explosive gas; and when at distant points the conditions of their oxidation were perfected, there were explosions, which caused the exhibitions of violence that form the boundaries of the undisturbed spaces. These facts of the conditions that prevailed at the origin of the disasters, place the rationale of their inception beyond question; showing that at some contained points, quantities of heat were generated and conveyed into the coal-dust, in which distillatory action was set up, which continued along the passages until stages were reached, where sufficient gas had been accumulated, and adequate atmospheric oxygen was obtainable; when explosions occurred closing the antecedent period of gas generation.

These undisturbed spaces at the origin of the explosions, were also

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[1] "Explosions in Coal Mines," p. 34. [2] Ibid., p. 56. [3] Ibid., p. 81. [4] "Report on the Explosion at Elemore Colliery," p. 14. [5] "Report upon the Explosion at Alltoft's Colliery," p. 5. [6] "Reports on the Disaster at Albion Colliery," p. 36. [7] "Reports on the Explosion at the Malago Vale Colliery," p. 15.

facts of observation at the Camerton and Timsbury Collieries, where the first gaseous explosions were localized, and their distances from the shot were measured. At Camerton Colliery the chemical activities were developed in both directions from the shot, and the initial gaseous explosions occurred at 136 yards on the inward side, and 140 yards on the outward side,[1] making a total of 277 yards; but both explosions exerted disruptive force back towards the shot, and the space free from any disturbance corresponding with that given in the gaseous mines, was 180 yards. At the Timsbury Colliery chemical activities were developed on the inward side only,[2] and the initial explosion occurred at 191 yards from the shot;[3] but the space free from disturbance was seventy-seven yards. It has been shown that both of these disasters were originated in the undisturbed spaces; and the rationale of their inception it will be remembered is identical with the description just given, of what must have occurred in the gaseous mines.

The propagations of the initial explosions will be readily understood by the explanation of their inception; and it is only necessary to recall the activities in the undisturbed spaces, to conceive their reinstitution by the large quantities of heat generated in the explosions, and their continuity through further distances in the passages, until the conditions of explosive ignitions were again completed. The repetition of these processes would naturally follow to the end of the propagations, and present the phenomena of successive local disruptions.

The spaces between the propagated explosions, though free from explosive violence, exhibited the effects due to immense thermal changes; the ordinary temperature being from 20°C to 25°C, while the educts of the coal were raised to the heat due to the partial combustion that was constantly going on, representing a temperature of over 2000°C. The educts at this exalted temperature, were travelling through the passages, heating the strata upon which they impinged; but were immediately followed by gases at the ordinary temperature, which were loaded with the condensed water arising from the oxidation of the hydrogen. The

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[1] "Coal-Dust an Explosive Agent," p. 29.

[2] Ante, pp. 48, 50. [3] Ante, p. 58.

old method of breaking the strata by heating with fire, and cooling with water, was therefore in operation, though only for a comparatively momentary period; but sufficiently to bring about disintegration of loose strata, and scaling of some faces of stone to which timber was wedged; all of which was observed in the Camerton Colliery Explosion.[1] Where the strata was favourable for this action, stones would fall, timber would be released and gravitate to the floor, and the passage left in a disarranged condition. The spaces between the explosions would not therefore present an absolute freedom from disturbance; but exhibit displacements of materials, by this silent but potent thermal agency.

The difference between these thermal effects and the results of explosive violence, has not been recognized in the records of explosions in gaseous mines; therefore the evidence upon the subject of local and separate explosive ignitions, is not so clear or full as it may have been. In the records of the disasters, however, there are descriptions of disruptive effects, that were essentially local, and demanded immediately adjacent explosions for their explanation; and extracts will now be given to complete the evidence upon this point.

The violent effects produced in the Durham explosions are described by Messrs. W. N. and J. B. Atkinson; and, speaking of the disruption at the Usworth Downcast Shaft, they remark:—"Its effects died out rapidly in the vicinity of the Shaft in all directions. Two men at the smaller Downcast Shaft forty yards away escaped alive. A pony in the loose box near was not injured. Men at the lower Level, eighteen yards below, were not seriously injured.[2]

About ninety yards from the Shaft there was a large space, in which a hauling engine and two multitubular boilers were erected, and it is recorded that: "The smoke-box door of the boiler nearest the Shaft was forced against the tubes. The safety valve was nearly torn off. The steam pipe, at its junction with the steam dome, was broken, and the gauge-glass was broken;"[3] and two men found there had been mutilated.[4]

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[1] "Coal-Dust an Explosive Agent," pp. 77, 78.

[2] "Explosions in Coal Mines," pp. 116, 117.

[3] Ibid., p. 75. [4] Ibid., p. 87.

The records state that the violent forces at the Shaft "Died out rapidly in the vicinity in all directions," and it would be difficult to find a clearer demonstration of a distinct and local explosion at that point. It is also observed that men who were forty yards from the Shaft escaped alive; but at the boilers ninety yards distant, one boiler was broken, and men killed and mutilated. Again the evidence is irresistible, that there was another distinct and local explosion at the boiler.

These two local explosions were about 1¼ miles from the point where the disaster originated; and therefore utterly remote from any explosive forces there; and this long length of intervening passage contained many corresponding local exhibitions of disruptive violence.

In the Alltoft's Colliery disaster there was great damage done at the bottom of the Shaft, the engines fixed there were broken and destroyed,[1] and a boy standing near was shockingly mutilated; the condition in which the body was found is thus described:—"Another boy was found near the engine-house. We found a leg, an arm, and part of the face, within twenty-four hours of the explosion; but it was not till a fortnight afterwards that we were led by the smell to find the other parts of the body. He was blown literally to pieces. One of the men drew my attention to the tub, and the skin was forced right through a slit to the inside.[2] Within forty to sixty yards of the engine, the bodies of other men were found, but they had suffered no violence, and were not disfigured. The mutilated condition of the boy shows that he was in the immediate presence of an explosion, and was subjected to its violent and shattering forces; but the bodies of the men forty to sixty yards away, were not damaged; therefore those violent forces must have been expended in the vicinity of the engine, and within the limited area of the observed disruptive effects. The distinct and local character of this explosion is consequently beyond question.

The origin of the disaster is placed about 550 yards from the engine; and mid-way between, there was a large fall 130 yards long extending in both directions from the edge of the pillar of coal supporting the Shafts;

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[1] "Reports on the Explosion at the Alltoft's Colliery," p. 4.

[2] "First Report Royal Commission upon Explosions from Coal-Dust," Question No. 3823.

one part being in the pillar, the other in the goaf. Between this fall and the origin of the disaster, the bodies of six men were lying, who had suffered neither violence nor disfigurement; and between the fall and the engine, there were the bodies of other men who had also escaped disfigurement; so that the men on the opposite sides of the fall, had not been exposed to the explosive violence by which it was caused; consequently a second local explosion, distinct from the disruption at the engine, must have occurred somewhere in this disturbance in the passage. Two separate explosions are therefore localized: one at the engine near the Shaft, the other about 270 yards away towards the origin of the disaster; and the plan of the workings which Mr. W. E. Garforth placed before the Royal Commission on Explosions from Coal-Dust, in which the disturbances are marked, shows many more isolated falls, at widely distant points throughout the mine, indicating numerous distinct *loci* of explosive violence.

The workings of the Elemore Colliery were divided into many districts, each one having its "Landing," where the coal trams from the faces were collected for despatch in the main haulage roads. These "Landings" were entirely distinct from each other, and at great distances apart; but they were found to have been the centres of very violent forces, the effects of which rapidly diminished on both sides. In the Moorsley Way end, the materials were hurled away in opposite directions. "The drum and spur wheel of a winch were found at a short distance outbye of the place where the winch stood,"[1] in the reverse direction to that from which the explosion was propagated. In the Hall Way, the "Rapper and its table were found some yards outbye, . . . and the Rapper lever and its guard some yards inbye."[2] In the Polka Way, "The explosion passed to the landing, blowing out the air crossing and breaking the tubs."[3] In the Derby Way, "The explosion passed with great force to the South Derby Landing, doing considerable damage to the tubs and other gearing."[4] In the East and West Derby Ways, "The explosion also extended to the Landing."[5] At the Derby West Way end, "There was another strong

[1], [2], [3], [4], [5], "Reports on the Explosion at Elemore Colliery," p. 15.

and distinct example of force acting in the contrary direction to that in which the explosion had travelled. Parts of the winch which stood near the Way end, were found at a distance of eleven, thirteen, and fifteen yards outbye from the original position. . . . Drum sheaves on the curve were forced some inward, and some outward."[1] In the Lady Hutton Seam at a lower level, "Tubs and timber appeared to have been blown in contrary directions. From the direction in which tubs and timber were blown in the Shaft siding, it would appear probable that the explosion passed both inbye and outbye, from the junction of Allen's Drift with the Engine Plane;[2] and clearer evidence could not be produced that there was an explosion in the junction which hurled the timber and tubs in the opposite directions in which they were found. The disturbance in the Derby West Way end upon another horizontal plane higher up the Shaft, and about a mile distant from it, affords equally conclusive evidence of a local explosion there; and the exhibitions of violence in all the other landings, demand local explosions for their explanation: as the forces necessary to shatter the tubs, to break and rupture mechanical appliances, tearing them from their erections and hurling them away in opposite directions, could only be generated by violent explosions in the immediate vicinity of these materials and erections.

The condition of the passages between these violent disturbances is recorded. Mr. Thomas Bell, H.M.'s Inspector of Mines, states in his Report that: "The aggregate length of main Intake airways which were traversed by the explosion, exceed 3500 yards . . . At many points, things which could easily have been moved, were not disturbed,[3] which completes the evidence that the exhibitions of violence were separated by lengths of road, in which movable materials were not disturbed: and that the shattered doors, tubs and timber, and wrecked machinery, fix the *loci* of separate and local explosions.

It has been already shown that this phenomenon of numerous local explosions, characterized the disasters at the Albion, Malago Vale, and

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[1] "Reports on the Explosion at Elemore Colliery," p. 15.

[2] Ibid., p. 15. [3] Ibid., p. 16.

Llanerch Collieries. It was so distinct in the explosion at the Risca Colliery, 1880, that Mr. J. Dickenson advanced the suggestion that there had been "Several subordinate explosions of subordinate accumulations"[1] of gas; and the records of the disasters at the Aberçarne, Altham, Blantyre, Bryn, Clifton Hall, Dinas, Hyde, Llan, Mardy, Mossfields, National, Penygraig, Seaham, Trimdon Grange, Tudhoe, Udston, and West Stanley Collieries, afford identical evidences of numerous *loci* of explosive violence.

The foregoing evidence leaves no room for question, that these calamities are characterized by numerous successive shattering explosions, corresponding with the facts observed in the disasters in non-gaseous mines.

These local explosions occurred at or near to large sectional areas in the passages, or where the ventilating current became concentrated by doors and obstructions. Violent disturbances were found at the shafts, doors, sidings, landings, and junctions at Seaham,[2] Trimdon Grange,[3] Tudhoe,[4] West Stanley,[5] and Usworth Collieries[6]; at doors, junctions, sidings, and Jig landings in Mossfield Colliery[7]; at the shaft, doors, junctions, and landings in Elemore Colliery[8]; at the shaft, engine-house, doors, and junctions in Alltoft's Colliery[9]; at the shaft, doors, and junctions in the Malago Vale Colliery[10]; at the engine-houses, doors, junctions, and sidings in the Albion Colliery[11]; and at corresponding places in the Abercarne, Altham, Blantyre, Bryn, Clifton Hall, Dinas, Hyde, Llan, Llanerch, Mardy, National, Penygraig, Risca, and Udstone Collieries, showing another identity with the phenomena in the Camerton and Timsbury Collieries.

The terminations of the explosive phenomena are found to occur under varied conditions. When they happen at the shafts, the gaseous products rush out into the open atmosphere in the form of clouds of

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[1] "Report upon the Explosion at Risca Colliery, 1880," pp. 13, 79, 80. [2] "Explosions in Coal Mines," pp. 32-35. [3] Ibid., pp. 46, 47. [4] Ibid., p. 56. [5] Ibid., p. 61. [6] Ibid., pp. 72-85. [7] "Reports on the Explosion at the Mossfield Colliery," pp. 8-10. [8] "Reports on the Explosion at Elemore Colliery," pp. 14, 15. [9] Plan, Appendix xii*a*, "Report Royal Commission on Explosions from Coal-Dust." [10] "Reports on the Explosion at the Malago Vale Collieries," 1891, pp. 8, 9. [11] "Reports on the Disaster at the Albion Colliery," pp. 16, 17, 35.

smoke and dust; on a few occasions only, flame has been observed in the cloud, as at Blantyre[1] and Elemore Collieries.[2]

In some of the underground workings, the phenomena was continuous into the coal faces. In the explosion at the Llanerch Colliery, the timber at several points of the coal faces was covered with coked coal-dust or burnt, and the blocks of freshly-cut coal which had just been filled into the trams "Was actually coked," showing that the chemical actions were in operation there.[3] At Trimdon Grange, West Stanley, and Usworth Collieries,[4] and at the Hyde,[5] Llan,[6] Clifton Hall,[7] Malago Vale,[8] Penygraig,[9] and Udstone[10] Collieries, the timber in some of the coal faces was also coated with coked coal-dust; while at the Albion Colliery, timber at the extremities of the workings in seven out of the eight districts (the extent of which may be conceived from the fact that they afforded room for 1000 men in the morning shift), were coated with coked coal-dust, or "Scorched"; and the faces of newly-cut blocks of coal loaded upon the trams, were coked.[11] In these Collieries, coal-dust was undergoing distillation in the vicinity of the working faces, and the educts had obviously undergone a great elevation of temperature.

In other parts of the workings of these mines, the explosive phenomena ceased at points long antecedent to the working faces; and this is true of nearly every explosion on record, of which voluminous evidence may be given, but which if quoted here would unnecessarily extend this already lengthy chapter. There are some districts or parts of districts in the mines, at the entrances of which, the explosive energies have exhibited disruptive force, and at limited distances beyond, the indications of the re-instituted chemical actions have suddenly ceased. These abrupt cessations of the explosive energies have

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[1] "Report upon the Explosion at Blantyre Colliery," p. vii. [2] "Reports on the Explosion at Elemore Colliery," p. 15. [3] "Report on the Llanerch Colliery Explosion," p. 9. [4] "Explosions in Coal Mines," pp. 48, 61, 86. [5] "Report upon the Explosion at the Hyde Colliery," p. 8. [6] "Proceedings Royal Society," vol. xxiv., p. 359. [7] "Report on the Explosion at Clifton Hall Colliery," p. 13. [8] Plan, with "Reports on the Explosion at the Malago Vale Colliery," 1891. [9] "Report upon the Explosion at the Penygraig Colliery," p. 96. [10] "Report on the Explosion at Udstone Colliery," p. 7. [11] "Reports upon the Disaster at the Albion Colliery," p. 35, and Plans.

occurred where the passages were dry, and where coal-dust was present; but they have also happened under partly opposite conditions, when the passages have been wet, instances of which are recorded in the explosions at the Alltoft's,[1] Albion,[2] Seaham, Trimdon Grange, Tudhoe, and Usworth Collieries.[3]

The phenomena at the terminations of the explosive energies in gaseous mines, are again found to be identical with what was observed at the Camerton and Timsbury Collieries, where smoke or dust issued out of the Upcast Shafts, distillatory action was in operation near to some coal faces, blocks of coal on loaded trams underwent destructive distillation, the chemical actions abruptly ceased in dry and dusty roads at considerable distances from the coal faces, and were also arrested in wet passages. The conditions that existed at these terminations, were investigated at the Camerton Colliery,[4] and have been considered in a preceding page of this volume in the inquiry into the explosion at the Timsbury Colliery,[5] and in both disasters small ventilating currents, impoverished or "Return" air, and wet passages, were found to have prevailed, and to have been adequate to bring the chemical activities to a close.

The abrupt terminations of explosive phenomena in gaseous and non-gaseous mines, are therefore caused by atmospherical conditions, in which heat could not be generated for their continuance, because there was inadequate oxygen to sustain the chemical actions by which the heat was produced; and also by wet surfaces, which demand the surrender of the heat when generated, for the evaporation of their moisture.

It will be readily recognized that wet passages must naturally arrest and quench the explosive energies, but the atmospheric conditions that bring about the same result, are not so visibly potent, and an illustration will assist the recognition of this fact.

One of the early effects in the Seaham Colliery explosion, was the destruction of the separation doors between the Downcast and Upcast

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[1] "Report Royal Commission upon Explosions from Coal-Dust," Question No. 3728. [2] "Reports upon the Disaster at the Albion Colliery," p. 34. [3] "Explosions in Coal Mines," p. 104. [4] "Coal-Dust an Explosive Agent," pp. 20, 27, 91-93. [5] Ante, pp. 65-67.

Shafts, which allowed the air to escape directly from one shaft to the other without going into the workings. The ventilation was therefore cut off, and there were no supplies of atmospheric oxygen to sustain the chemical actions that brought about the explosions, except what were already in the roads; and these were being constantly used up by the explosive ignitions and their antecedent actions; consequently stages were at length reached where the oxygen was inadequate to meet the demands, resulting in a cessation of the distillatory action: and propagation terminated in the In-take air roads of the three districts, at considerable distances from the coal faces.

In the Albion Colliery explosion, one of the first effects was also the destruction of the stoppings and doors between the Downcast and Upcast Shafts, and therefore the suspension of the supplies of air to the workings. The In-take air roads from the Downcast Shaft to the coal faces, were shorter than the In-takes at Seaham Colliery, and the volume of air in circulation to those points much greater; the quantities being, Seaham Colliery, 107,750 cubic feet per minute,[1] Albion Colliery, 198,170 cubic feet per minute.[2] The chemical actions were in progress into the coal faces at the Albion Colliery, where coked residues were deposited on the timber. The educts also had gained such an elevation of temperature that blocks of coal on the loaded trams were subjected to destructive distillation, and the faces of the timber were burnt. The continuity of the distillatory action into the extreme ends of the workings at the Albion Colliery, and their failure at considerable distances from the coal faces at Seaham Colliery, are therefore coincident with an immense difference in the quantities of air in circulation. For each renewal of pure air at Seaham Colliery, there were more than two renewals at Albion Colliery; consequently the latter would contain less oxidized products, and much more available oxygen. Undoubtedly there are local conditions affecting the state of the air in different mines; but the strength of the above comparison is obvious, and shows that the difference in the development and extent of the chemical actions,

[1] "Explosions in Coal Mines," p. 31.

[2] "Reports upon the Disaster at the Albion Colliery," p. 30.

has its explanation in the quantities and qualities of air at their command.

The coked residues at the coal faces in the Albion, Malago Vale, Hyde, Penygraig, Llan, Llanerch, Clifton Hall, Udston, Trimdon Grange and West Stanley Collieries, show that the coal there was undergoing distillation, from which gaseous hydrocarbons were filling into the passages, and that the timber and trams of coal were enveloped in gases at an exalted temperature.

Explosive gas and ignition temperature were present at these points, but there were no explosions: the timber was undisturbed, the trams were undamaged and unmoved, and their contained coal was not dislodged; therefore the absence of explosions could only have been due to the want of the atmospheric oxygen, which was the only element required to complete the explosive cycle.

These illustrations will show the important place the atmospheric conditions occupy in explosions; and it is only necessary to recall the fact, that oxygen is as essential to an explosion, as the explosive gas itself: to recognize the conclusiveness of the argument, that propagation of an explosion must fail in the conditions of the air currents that have been observed.

The phenomena of explosions in gaseous and non-gaseous mines, from their origin to their terminations, have now been examined and compared, with the result that they are found to be identical, in every fundamental feature. The first question considered, *viz.*, the products of the oxidations in the explosions, is probably the most important, because of the scientific certainty that attaches to the inductions that have been drawn. The absence of any appreciable quantity of carbon dioxide in the products of the explosive ignitions and their antecedent actions; the fact that candles and lamps burned brightly in the atmosphere that filled the passages after these oxidations and before any fresh supply of air could be introduced into them; the physiological sensations experienced in that atmosphere; the enormous quantities of heat generated in those oxidations; and the freedom with which the products surrendered their heat to wet surfaces; are demonstrative evidence that the products of the explosions in both classes of mines, were produced by

the oxidation of the same gases: and consequently, that the gases that were exploded in the gaseous and non-gaseous mines, were identical.

These products are fundamentally different from the products of the explosion of fire-damp: therefore fire-damp was not appreciably present; and the only other explosive gas that could have been conceivably present, which by its oxidation yields products that would permit the effects that were observed, was hydrogen: and the preceding investigations show that there is no room for doubt, that it is to the oxidation of hydrogen, that explosions in coal mining are due, as the constitution of the after-damp cannot be otherwise explained.

The sources of the hydrogen have been traced to the coal-dust in the mines. The solid residues of coke that are produced by the destructive distillation of coal, were found in the field of disaster at most of the Collieries; but the carbon constituent of gaseous hydrocarbons was an universal phenomenon, proving that these gases had been evolved in the mine passages, and had undergone dissociation yielding the free hydrogen, which investigation has shown must have been present.

The explosions were originated by the heat generated in the oxidation of either a solid explosive, or a body of fire-damp. Their inception was characterized by an absence of explosive violence, and by the generation of gas from the coal-dust through undisturbed lengths of the passages, which was ultimately exploded, at various distances from the origin of the activities, causing the initial gaseous explosions.

The initial gaseous explosions were propagated in various directions through the mines, and the disasters present the phenomenon of distinct explosions, separated by intervals in time and space; the bodies of gas that were successively exploded, being evolved in antecedent lengths of road: each explosion occurring in large sectional areas or where the oxygen was to be obtained, and generating the heat to renew the chemical actions in the succeeding intervals.

The termination of each branch of propagation is characterized by a wet length of passage, or the absence of atmospheric oxygen to sustain the chemical actions.

The inception and development of these explosions in the coal-dust on the floor of the roads, is now demonstrated; and the mystery that

has surrounded so many disasters, disappears with the knowledge, that it is no longer necessary to assume there were sudden blowers or accumulations of fire-damp, instantaneously filling up thousands of yards of workings; as there was already at hand in the coal-dust lying upon the passages of the mine, a practically unlimited supply of gaseous educts, capable of giving rise to explosion. These educts were obtained by processes which were originated by the surplus heat of an ordinary charge of explosive, or by the heat generated in the ignition of a body of fire-damp: and when the activities were initiated, they carried destruction and death into the workings where oxygen was available, and there were no wet spaces to break down the temperature.

To conclude, the theory advanced in this book is, that the solution of the calamities that darken the history of coal mining, demands no assumption of the sudden and incredible accumulation of an explosive agent: but that the presence of coal-dust, must give rise to all the observed phenomena.

CONCLUSION.

THE Royal Commission upon Accidents in Mines in their Final Report (1886) expressed the view, then prevailing in the Mining world, that coal-dust was not an explosive agent; otherwise it was assumed that explosions would be of daily occurrence. This conclusion was founded upon the belief that all the past explosions were due to fire-damp, inasmuch as they had occurred in gaseous mines. Since that date two explosions have occurred in non-gaseous mines, the phenomena of which, have been minutely observed and recorded as a foundation for investigating the causes and nature of colliery explosions; and upon comparing these observations with the phenomena of explosions in gaseous mines, they are found to present a correspondence, that demonstrates their identity in origin, explosive agent, and rationale; and as coal-dust is the only agent common to the two classes of mines, it must have been the source of the identical phenomena they exhibit. This conclusion, however, has been shown to have a foundation in facts of observation and science; and therefore the views of the Royal Commission are now seen to have been founded upon a mistaken view, when they regarded fire-damp, as the explosive agent in the disasters in gaseous mines. Its absence has been now demonstrated; and coal-dust proved to be the source of the gas that caused the calamities. With the evidences of the explosions at the Camerton and Timsbury Collieries, and their correlation with the records of large explosions in gaseous mines, it is placed absolutely beyond question, that coal-dust was the explosive agent in these calamities; therefore the difficulty which the Commissioners' views presented, in accepting this conclusion as to the character of coal-dust, must now disappear.

Another difficulty in the coal-dust question was, the historical freedom of non-gaseous mines from explosions, though the dust was

distributed in their workings as freely as in gaseous mines; but this objection does not appear difficult to answer, if the discussions upon the failures in propagation in this and the Author's previous work be recalled. Increased ventilation has been the remedy urged for the prevention of explosions; and when fire-damp has appeared in mines, the air-currents have been immediately enlarged; the quantities of air circulating in gaseous mines are therefore much greater, than in non-gaseous mines. The effect of these rapid and quickly renewed currents, was certainly to dilute and render harmless all noxious gases, including fire-damp; but they inevitably removed the moisture in the workings, dried up the coal-dust, and supplied large volumes of atmospheric oxygen; and these effects were produced especially during the months of the year when the surface temperature was low, because of greater difference of weight of motive column, increasing the volumes and velocities of the ventilating currents to their maximum. The coal-dust was therefore in a favourable condition for destructive distillation, ample supplies of atmospheric oxygen were available for chemical actions, there were no great demands for heat to vaporize moisture, because it had been already vaporized by the rapid air-currents; therefore, in these circumstances, when heat was suddenly generated, it was wholly available for distillatory action, and processes were initiated that ended in disaster.

The volumes and velocities of air circulating in non-gaseous mines, being a fraction compared with what prevailed in gaseous mines, the walls of the roads, and the small coal, retained a measure of moisture. Any sudden accession of heat would necessarily be first employed in vaporizing that moisture; and, recalling the high specific heat of water, it will be evident that the quantity of heat generated by the ignition of an ordinary charge of solid explosive, would be chiefly, if not wholly, expended in that work of vaporization, and practically there could be none left to effect distillatory action. From what is known also of the demands of oxygen to sustain the series of chemical changes, which it has been seen must precede an explosion, it will be manifest that they cannot be satisfied in small currents, or impoverished air. The initiation of an explosion in non-gaseous mines, was therefore confronted by two antagonistic conditions, viz., an amount of moisture, that largely, or

wholly demanded the available heat for its vaporization, and small air-currents, inadequate to supply the oxygen required by these chemical actions.

In the old methods of ventilation in the Somersetshire non-gaseous mines, with small currents of low velocities, no explosion occurred; but at the Camerton and Timsbury Collieries the ventilation was largely augmented, and having to pass through the old sectional areas of air-way, the velocities were greatly increased, and the conditions approached to a comparison with those existing in gaseous mines; producing a corresponding state of the air passages and coal-dust, and providing larger supplies of oxygen. Within about six months of the increase in the ventilation, explosions occurred at both mines, which were brought about by the gases distilled from the coal-dust.

It will therefore be seen that, notwithstanding what has been laid down by the Royal Commission (Accidents in Mines), and the absence until recently of explosions in non-gaseous mines, that in the coal-dust that accumulates upon the floor of the mine passages, there is a peril of immense potentiality: which, once brought into action, is irresistible in its development throughout the mine, unless the temperature be broken down by wet lengths of road, or the chemical actions fail for want of oxygen.

The positiveness of this danger is disclosed in the fact, that the small quantity of coal-dust necessary to a disaster, is always present in roads through which coal has been conveyed; and that the surplus heat in ordinary charges of fired explosives, or in the ignition of fire-damp, is sufficient to bring about its development.

The coal worked at Camerton and Timsbury Collieries contains 35·55 per cent. of volatile matter, and it was natural to suppose that this large gas producing power, was largely responsible for the disasters in these mines; but the coal at the Albion Colliery yields only 15·19 per cent. of volatile matter, which proved adequate to cause the calamity that occurred there, in which it will be remembered there were extensive deposits of coked residues: showing that the gas had been distilled from the coal-dust; and by recalling the discussion of the explosion upon a preceding page of this work, it will be seen that it is a dangerous fallacy

to suppose, that the South Wales coal which yields a comparatively small quantity of gas on distillation, will not produce sufficient to cause a widespread calamity.

The many explosions, the origin of which can be traced to shot-firing, show the risk attending the employment of explosives; and although the number of shots that may have caused disasters, is almost an infinitely small fraction of the number that are fired annually in mines without any accident; still the calamities that have been caused by these means, are so terrible in their character, that though it may be, only one shot in half-a-million causes a catastrophe, to neglect to guard against it, would be criminal.

The important point to be considered in the employment of explosives, is manifestly that element which constitutes their danger; and to confine attention to the presence or absence of visible flame upon their ignition, or of inflammable bodies in the products of their combustion, is to linger upon the fringe of the question. The essential danger in an explosive, is the heat energy it develops; and if that energy could be wholly expended in the work of disintegrating the strata, no danger could arise from this cause; but in the nature of the case, it is practically impossible to adjust the charge of explosive to the exact demands of the work contemplated, and there is a surplus of energy in almost every charge that is fired. Sir Frederick Abel, suggested many years ago, that small charges of violent explosives enclosed in cartridges surrounded with water, might be used without igniting an explosive atmosphere; but it required more care for its effective adoption than could be obtained in ordinary shot-firing. In the absence of this water jacket; or of any means in the shot hole for the expenditure of the surplus heat, it is conveyed in the products of combustion, which are driven in sheets through the planes of rupture, and expended upon the first opposing surfaces. If these surfaces be dry coal-dust, distillatory action will be initiated, which is the beginning of disaster. The essence of the question is therefore the surplus heat, or if the shot be blown out, the total heat in the charge; and the danger is in this heat becoming available for distillation of the coal-dust. If the mine passage and the coal-dust be dry, and the products of combustion are propelled into the coal before

suffering any sensible dissipation in the atmosphere, distillation must follow, with the evolution of gaseous hydrocarbons. If the coal-dust and the walls of the mine passage be damp, the heat generated by the explosive is at once drawn upon to vaporize this moisture; and it depends upon the quantity of water, whether or not the heat is expended in this way, or to such an extent, that the coal-dust cannot be appreciably attacked.

In the high explosives, the heat energy is developed with immense rapidity, the coal is more or less shattered and diminished in value, and the rock is burst out with less than the possible economic effect. In mining powder the combustion is slower, producing a heaving and rending action, which loosens a larger extent of coal face, yields more screened coal, in better condition for transit; and also loosens a wider range of rock, which can be readily removed by pick or wedge; consequently the products of its combustion are spread over a larger area of rupture, and the surplus heat is therefore more effectively dissipated.

The heat energy and products of combustion of mining powder, have been determined by Sir Frederick Abel and Sir Andrew Noble;[1] and similar determinations of Nitro-glycerine have been made by Berthelot,[2] and Messrs. William Macnab and E. Ristori.[3]

Mining powder produces 48·65 per cent. of solid matter, including water, and 51·35 per cent. of gaseous products; of which 19·98 are combustible; and 1 gramme generates 516·8 units of heat: the unit being the heat required to raise 1 gramme of water from 0°C to 1°C. Nitro-glycerine yields wholly gaseous products, with the exception of water, but no combustible gases, and 1 gramme generates 1600 of these units of heat.[4] Messrs. Macnab and Ristori give 1652 units.[5]

The important difference between Mining powder and Nitro-glycerine, is not in the nature of their products, but in the quantities of heat they respectively generate; as, given equal charges of 12½ ounces of these explosives (the quantity in the shots at the Camerton and Timsbury

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[1] "Philosophical Transactions," vols. clxv., clxxi. [2] "Explosives and their Power."

[3] "Proceedings of the Royal Society," vol. lvi.

[4] "Explosives and their Power," p. 16. [5] "Proceedings Royal Society," vol. lvi., p. 15.

Collieries), the Mining powder would yield 183,141 units of heat, while the Nitro-glycerine would generate 567,000 units; and it is obvious that when the surplus heat of the powder had been exhausted in vaporizing the moisture of the coal-dust, there would remain in the products of the Nitro-glycerine an amount of heat energy, representing more than twice the original amount in the powder, to institute distillatory action, and cause disaster.

It is not necessary to carry this subject further, to show that the question of shot-firing in mines, depends upon the heat developed by the explosives; and that to displace Mining powder by a "High Explosive," that generates a greater quantity of heat, is to increase the danger; though it may possibly be subsequently reduced by the conditions under which the products of combustion are made to surrender their heat. But it must not be forgotten, that the heat of the Mining powder is much more effectively dissipated, than the heat of the "High Explosives;" because the powder by its slower combustion, ruptures a larger area of coal and strata, in which its products are dispersed, and the heat disseminated, so that by the time it comes in contact with the coal-dust, its energy is much more attenuated, or exhausted.

In 1893, Mr. H. Hall, H.M.'s Inspector of Mines, made some experiments with coal-dust for the Royal Commission enquiring into the subject, by firing charges of explosive in a shaft, the air of which was heavily laden with coal-dust. When Mining powder was fired into the atmosphere of coal-dust, there were very many ignitions of the dust, and with violence; but no ignitions of the dust cloud could be produced, when Roburite and Ammonite ("High Explosives") were fired into it; and upon these evidences, the total exclusion of Mining powder from mines, was advocated, and the adoption of certain "High Explosives" recommended; but the reason why these explosives behaved so differently, was not considered. When it is remembered that the cannon in which the charges of explosive were fired, was vertically suspended at the bottom of the shaft, its axis corresponding with the axis of the shaft: it will be seen that the products of combustion were projected up the open pit, at the velocities due to the rapidity with which the heat was generated in the charges. The bore of the cannon was only two feet

long, and it was nearly filled to the muzzle with the charge of explosive and coal-dust tamping; so that the products of combustion were immediately projected into the dust-laden air, with the projectile velocity due to each explosive. The charge of Mining powder undergoing slow combustion, propelled its products to a limited distance, at a velocity, which permitted lateral expansion from the mouth of the cannon, and which allowed the heat to institute chemical actions in the suspended coal-dust; and the discussions in this volume have shown, that once these actions are initiated, all the subsequent phenomena observed by Mr. Hall, follow as a natural effect, and would do so whether that initiation be caused by the heat in the products of Mining powder, a "High Explosive," or fire-damp.

The Roburite and Ammonite undergoing detonation, propelled their products at a velocity greatly exceeding that of the Mining powder, which necessarily disallowed of equal lateral expansion in the vicinity of the muzzle of the cannon, and which caused them to pierce through the dust cloud to the much greater height, due to the larger initial velocity. The heat therefore passed through the coal-dust, with a rapidity, which would not permit chemical action to be initiated; and being diffused through a considerable height of the Shaft, and consequently a much greater volume of dust cloud, was dissipated, and the coal-dust was not ignited.

The difference in the behaviour of these explosives, was therefore due to the great disparity in the volumes of dust-laden air, in which their products of combustion, surrendered their heat. With Mining powder, the velocity of propulsion from the cannon, allowed the heat to be concentrated in a limited volume of dust-laden air, and its application to the particles of coal for a sufficient period to initiate chemical actions. With Roburite and Ammonite, the higher velocity of propulsion due to their detonation or instantaneous generation of heat, diffused that heat through a much greater volume of dust-laden air, and did not permit contact with the particles of coal of the necessary duration to institute chemical actions, before the temperature of distillation was broken down.

If the conditions of these experiments compared with the conditions of shot-firing in mines: then on the question of the initiation of chemical

actions in the coal-dust only, the "High Explosives" would be the safer to use; but they cannot be so compared. The shots in mines are fired at all inclinations, in small and tortuous tunnels, so that there is no unlimited open and free space, the axis of which corresponds with the axis of the shot hole (like that provided by the vertical Shaft), through which the products of combustion may be driven, until the dissipation of their heat is effected. In shot-firing in mines, the products of combustion escape through the planes of rupture in the coal or the strata, as well as along the axis of the hole corresponding with the cannon; and are spread abroad in the tunnel; therefore the greater velocities of projection in the "High Explosives," simply effect a more rapid propulsion of the products of combustion against the surrounding and opposing faces, be they the roof, floor, or side walls; and the heat is concentrated in the coal-dust upon these faces. If that heat be adequate to vaporize the moisture present, and initiate chemical processes in the coal-dust; it is obvious that these processes will be instituted regardless of the velocities (within the limits of explosive projection) with which the heat is conveyed to that coal-dust. If charges of Mining powder, Roburite, and Ammonite, were fired as in ordinary mining operations, and in corresponding positions, so that their products of combustion were propelled against opposing surfaces in the vicinity of the shot hole, and those products contained equal quantities of heat; identical effects upon the coal-dust upon these faces must follow.

To form definite conclusions therefore upon the visible phenomena in Mr. Hall's experiments, would be to take a position of insecurity.

The primary question for consideration in the experiments, is the quantities of heat generated by the respective explosives; and secondly the conditions under which that heat becomes available for effective expenditure in distillation of the suspended particles of coal-dust; and this back history of what was taking place in the vicinity of the cannon at the bottom of the Shaft, is essential to a correct knowledge of the behaviour of the products of their combustion in such dust-laden air. Without such knowledge it is impossible to draw accurate conclusions as to the comparative safety of these explosives.

By the instantaneous generation of the heat energy, which is a

distinctive feature of "High Explosives;" the ignition of coal-dust can probably be avoided if it be suspended in a vertical column of air immediately adjoining the surface atmosphere; but if coal-dust be confined as it is in the contracted space of a road in a mine, the supposed safety due to the instantaneous generation of heat, and the consequent superior velocity of the movement of the vehicle of this heat, has no existence. The quantities of available heat being equal, the difference between "High Explosives" and Mining powder, is in the rapidity with which their heat is conveyed to the coal-dust, and with which the chemical actions are initiated.

The "High Explosives" have not yet been subjected to sufficient investigation, to determine whether they can be properly used in mines with less precautions than experience has shown to be necessary in the employment of Mining powder; and the suggestions that have been made in recent years, that these bodies should be preferred to Mining powder for use in coal mines, cannot at present be pronounced upon.

The danger in the employment of explosives being the heat available in their oxidation, the remedy is manifestly the provision of a material of high specific heat, to effect its harmless expenditure in the vicinity of the shot. Water presents a simple and inexpensive body of this character. To change one pound of water into steam at 100°C requires 288,938 gramme units of heat, and therefore if the entire heat in a charge of 12½ ounces of Mining powder, could be directed into one pound of water at 0°C, it would be entirely expended in converting about two-thirds of that water into steam.

The distribution of the water requires attention, if the coal is to be effectively protected from distillation. It has been shown that when once the chemical processes are instituted in coal-dust, heat is generated with such great rapidity, that a condition of mere dampness of the coal fails to arrest their progress. The surfaces of the road that are exposed to the action of the heat, must therefore be made wet, with a quantity of water largely in excess of that which would be vaporized, by the entire heat in the explosive employed.

At Camerton and Timsbury Collieries the coal-dust was damp in places. At Llanerch Colliery the conditions were less favourable still for

distillation. Mr. J. S. Martin, H.M.'s Inspector of Mines, in his Report upon the Llanerch Colliery Explosion states that, "The workings were far from being 'dry and dusty' as hitherto ordinarily interpreted, but dust of a more or less heavy nature undoubtedly existed in places, and must have played an important part in extending the flame and effects of the initial explosion; that the quantity of fine and light dust existing, was comparatively little, was borne out by the absence of much dust on the timbers after the explosion. In only very few places, were the timbers thickly coated with dust or charred dust, such as is usually found after explosions where considerable quantities of dust existed in the workings. . . . . I have no hesitation in saying that there is not a 'dry and dusty' mine in the Rhondda steam coal series where artificial watering is carried out, to be compared as regards dampness, with this Colliery at the time the explosion occurred" (Annual Report, 1890, page 15).

This dampness at the Camerton, Timsbury, and Llanerch Collieries, entirely failed to exhaust the heat generated by the chemical actions in the coal, when once they were initiated; and as a matter of fact, that exhaustion has only been known to have been effected by the intervention of considerable lengths of wet road.

The quantities of heat generated by the ignition of mining powder and several of the high explosives, are known, and the amounts of water necessary to bring about the expenditure of that heat, are simply questions of arithmetical computation; but the heat generated in the chemical processes set up in the coal-dust, can only be estimated; and its magnitude can be conceived by the immense amount of dampness that must have been vaporized at Llanerch Colliery; and in the extent of wet surfaces necessary to effect the surrender of its energy.

The important distinction between the quantity of heat to be dealt with at the inception of the disaster: and that in the subsequent stages, will now be obvious; in the former case it is simple in quantity and under complete control; in the latter it possesses an irresistible potentiality in the ordinary conditions of a mine, as is shown by the miles of propagation it effects, even when there are intervening spaces of damp coal.

The disquieting fact that the heat energy in an ordinary charge of explosive, can originate a devastating explosion in a mine, is

therefore divested of some of its terror, by the knowledge, that the heat at the inception of the disaster can be made to surrender its energy, by a simple and intelligent application of water thoroughly applied. Consequently the disasters that are produced by shot-firing, can be stopped at their origin.

It is necessary to emphasize the fact that small coal upon the floor of the roads, is subjected to distillation, and though there was no observable quantity of fine coal-dust in the Llanerch Colliery, an explosion occurred there, in which 176 lives were lost. Further, that only a trifling quantity of small coal (too scanty to be removed, and not readily observed), is required to yield the explosive gases; therefore the necessities of the case demand that the surfaces of small coal and coal-dust, though in admixture with non-combustible matter, should be effectively watered immediately before firing a shot, except where these surfaces are normally wet.

In the ordinary course of mining, it is part of a miner's training to learn the methods of using explosives, and to become habituated in their use; and in collieries where explosives are generally employed, a skilled miner is considered competent to bore shot holes, and charge and fire them. In many mines, therefore, a large number of the miners are practically trained in the use of explosives, and employ them almost daily. It is therefore essential that the watering to be carried out before shot-firing, should be clearly set out in a Special Rule, so that the regulation may carry statutory authority, and become operative under heavy penalties.

It will be remembered that the explosions at the Llanerch and Malago Vale Collieries, in 1890 and 1891, were originated by the heat generated in the ignition of fire-damp; and there can be no doubt that the origin of many of the other calamities in gaseous mines was due to the same cause; but there is no available data upon which to form a reliable conception of the volume of gas which will produce this effect. The heat energy generated by fire-damp, and that generated by solid explosives, differ in their conditions and are not equally effective for distillation. In shot-firing, there is a concentration of the energy in the coal-dust, or in the small coal on the floor; but there is no corresponding concentration

of the energy from ignited fire-damp, which before ignition is in a free gaseous state, in contrast with the confined and solid condition of the explosive. Instead of occupying a volume of a few cubic inches like an explosive, fire-damp fills many cubic feet of the passage, in the free air of which it is rapidly expanded at the expense of its heat, and considerably more is lost by conduction.

A much greater quantity of heat would therefore be required to be generated to bring about the chemical actions in the coal, when the source of that heat is in ignited fire-damp, than would be necessary if it were in a charge of explosive. In the absence of accurate knowledge of the volume of gas required to generate that quantity of heat which would be dangerous in the conditions in the mine; or of any control, or knowledge of the volume of gas that diffuses into the mine passages, or the time of its issue; the gravity of the danger demands the exclusion of naked lights from every mine in which fire-damp is found. The removal of the accumulated small coal from the roads, and the regular watering, or constant injection of water in a state of vapour into the air of the main intakes, also becomes a precaution of great importance.

An observation upon the importance of the records of the hygrometer, arises out of the Timsbury Colliery Explosion. Barometrical observations have received considerable attention, as affording warning of the conditions favourable to the diffusion of fire-damp into the air currents of the mine; and it is now manifest that observations to disclose the hygroscopic condition of the air entering the Downcast Shaft, are of no less importance, as indicating the state of the air currents for bringing about a favourable condition of the walls of the passages, and of the coal distributed through them, for the initiation of very dangerous activities, if the heat energy generated by an explosive, or by ignited fire-damp, become available.

Continuous records of the hygroscopical condition of the air entering the Shaft, should now form part of the observations at a mine.

The subject ot ventilation is also seen to demand attention beyond the necessity of diluting and rendering harmless all noxious gases; for though gaseous exhalations may be reduced to an innocuous condition by circulating large volumes of air through the mine, necessarily at

high velocities; it must not be forgotten that their evaporative effect upon the moisture of the workings, and the small coal distributed universally through them, causes another danger, which must be an element in the consideration of the subject.

The investigation of the nature of Colliery Explosions contemplated in the preparation of this volume is now completed, and the Author thinks that the views he has advanced upon the subject, built upon his personal observations; and which are found to have confirmation in the records of phenomena of explosions made by many mining engineers, will be of interest to others who are also giving thought and time to the subject, and especially to those who are associated with the management of collieries, whose experience in colliery operations will enable them to readily follow the facts and arguments.

The rationale of a Colliery Explosion advanced by the Author in "Coal-Dust an Explosive Agent," and further developed in this work, he ventures to hope will help to give such a grasp of the nature of the danger to be guarded against, as will strengthen the hands of all engaged in colliery operations in contending with it; so that in future the coal supplies may be obtained without the terrible sacrifice of life the explosions have entailed.

APPENDIX.

In the official investigation of the Timsbury Colliery Explosion, Mr. John Batey, one of the Mining Engineers acting for the owners, adopted an idea that was advanced many years ago, and which had been recently revived by Professor Vivian B. Lewes, that carbon monoxide was the gas exploded; and suggested that the disaster was due to that gas in admixture with coal-dust. The evidence offered in its favour was that the part of the communication in which the shot was fired, was in old workings on the Great Seam, which had been closed thirty-six years previously; and that the entrances of three old roads which were stopped up prior to the explosion were subsequently found opened up. One of these roads, A, (Plate I.) was ninety-four yards on Lower Conygre side of the shot, and a shell of stone-work was built at its entrance, forming the side wall of the communication. The other two roads, B and C, (Plate I.) were fourteen and thirty yards respectively, upon Upper Conygre side of the shot; and these were stopped up, but with loose stones and *débris*. At six yards from the shot towards B, there was an irregular narrow guttered cavity in the roof of the communication, about four yards long, due to cross jointing in the strata: which had no connection with the old workings or the road B; and was timbered in the usual manner with posts and collars. This cavity was about four feet high at the maximum, above the roof of the communication, and tapered out irregularly to nothing at either end, and at the sides; and was partly filled with the stones and *débris* it yielded, which were laid upon the timber. After the explosion Mr. Batey examined this cavity with a Stokes' Alcohol flame lamp, and his evidence is as follows:—"The lamp clearly exhibited indications of something unusual in the flame, and the same appearance he discovered at a high point near the roof of the Great Vein inner road at the stopping about fourteen yards in. He believed these

traces to be carbonic oxide, caused by the extensive use of gunpowder, or by the heating of the gobs of the Great Vein over the area of the old workings referred to. If a portion of that gas was present prior to the explosion, as he believed it was, either in the cavity of the roof or the Great Vein road near there, they had the means in the presence of coal-dust which was lodged unseen upon the timber and *débris*, of setting up an explosion. . . . . He believed that the explosion originated somewhere between the shot hole and the Slyving Vein in Peter's Gug . . . most likely at the first or second old road end on the Great Vein inside the shot."[1]

When the explosion occurred, the entrances to the roads A, B and C, were closed by air-tight stoppings, to prevent the air leaking away from the Main In-take; and any gases in the old workings were sealed in, so that they could not escape out into the communication. After the explosion, the timbering at the cavity, and at the road C were found undisturbed; but the materials forming the stoppings at A and B, were scattered over the floor of the communication.

The explosion necessarily effected the combustion of any inflammable gas in the mine, and entirely changed its atmosphere into the products of the gases that were oxidized: which filled into all roads that were open, old or new; and as the stoppings at A, B and C had been broken down, these roads must also have been filled with the products. When the ventilation was restored, these products were swept out of the roads through which the air currents passed, but they remained in the old roads which were not ventilated, until in process of time, they had diffused out into the circulating air. Mr. Batey's examination of the air in the cavity and in the old road near, were made in these altered conditions after the disaster; and if there were reliable flame tests, for the detection of carbon monoxide, and those tests revealed its presence at the points named at that period, that would be inadequate to sustain the suggestion that it existed there before the explosion.

The old roads being sealed up, the cavity was the only possible

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[1] "The Western Daily Press," "Bristol Times and Mirror," and "Bristol Mercury," March 1st, 1895.

locus for the carbon monoxide; and it is difficult to conceive its origin, no less than its existence in such a place in the Main In-take Airway. Gob fires have never been known in the Collieries, and shot firing was as a rule only carried on at the working faces, quite remote from those old roads, and the communication. Some shots with mining powder had been fired a short time previously, between the shot that originated the disaster and Peter's Incline; but as a current of about 10,000 cubic feet of air was passing at a velocity of over 300 feet per minute, the small quantity of carbon monoxide with its associated carbon dioxide, nitrogen, and other gases, produced by a charge of powder, would be diluted to the vanishing point, and swept away with the current immediately it was formed, in the opposite direction to that in which the cavity lay. It is impossible to conceive, therefore, where the carbon monoxide could have been produced, or how it could have been secreted in the cavity, in the circumstances of the volume and velocity of the air current sweeping under it. Carbon monoxide is only of slightly less density than air, and the cavity was practically open to the air current, the interstitial spaces of the timber comparing with rough trellis-work, with a large hole on one side. The air current in striking the opposing faces of the timber, would be partly deflected into the cavity; and local eddies and currents thus produced, must with diffusion, have kept the cavity filled with air, and disallowed the presence of carbon monoxide.

At every place in the mine where explosive violence was exerted, the timbering was displaced and often broken: but the timbering at the cavity was undisturbed, therefore there could have been no explosion of carbon monoxide or any other gas there, nor in its vicinity.

The materials of the stopping at the entrance of the adjacent road B, were scattered into the communication itself, in the opposite direction to what must have resulted from an explosion there; and which demands for its explanation some force from behind, in the old workings.

The timbering at the road C was also undisturbed, and the food bag was found hanging where it had been placed, showing no explosion had occurred there; therefore it was obvious that no explosion could have occurred at the cavity or at the roads B and C. A short distance beyond

there were empty trams in the siding, and at the foot of Peter's Incline there were more, and neither of them were injured; but at the top of Peter's Incline it will be remembered, the trams were broken up and crumpled, and afforded direct evidence that the initial gaseous explosion had occurred at that place.

The question remains whether carbon monoxide was in the air current from the shot to the top of Peter's Incline, to produce with coal-dust the initial gaseous explosion. The deceased man Carter charged the hole and lighted the shot, and walked to the foot of Peter's Incline, and was subsequently found burnt and dead; therefore it is manifest that there was not one half of one per cent. of carbon monoxide (the quantity fatal to human life) in the air, or he would have been poisoned before he had finished the charge, or reached his Refuge hole. But he was burnt, and found in an attitude seeking protection, which showed he was conscious after the disaster: and that when the hot gases reached him, the air current did not contain any appreciable fraction of carbon monoxide; nor was he mutilated, indicating that he had not been exposed to explosive violence. The air current was the main intake, the Downcast Shaft was not far distant, and it is beyond question that the air current was free from the gas under notice.

Upon the opposite side of the shot towards Lower Conygre, the only disturbance was the displacement of the stopping in the road A. The materials were also scattered into the communication, again showing that the disturbance had been occasioned not by an explosion there, but by some force from behind the stopping, and in the old workings.

Since the disaster, the character of the gases in the old roads has been somewhat cleared up. In the two roads B and C, the stoppings were re-built and pipes inserted, for the purpose of ascertaining if the normal exhalations of the old workings contained carbon monoxide gas as was suggested. During the Author's inspections on March 6th and 7th, he examined those places; the stoppings had been so far restored, that these exhalations were passing through the pipes; but they caused no physical sensation when deeply inspired, therefore they did not contain carbon monoxide; and the odour resembled that of stagnant air. At the same time the flow of gases through

the pipes fluctuated considerably, sometimes rushing out of the pipes, and at others ceasing to flow at all; and it was obvious that they were subjected to some irregular force from behind. The explanation, however, was not far to seek; the old roads had indirect communications with one of the shafts, and their contained air was subject to the pulsations produced by the ascent and descent of the cage, which caused the ebb and flow at the pipes in the stoppings. The air in the old roads A, B, and C, was therefore subjected to the alternate compression and contraction caused by the descent and ascent of the cage, and in such circumstances it must have corresponded with the air in that shaft, and consequently contained no carbon monoxide nor any inflammable gas.

The displacement of the stoppings at A and B, into the communication, is now accounted for. These stoppings were simply put in to keep the air current from leaking out of the communication, and no pressure from behind was contemplated in their construction, as they were simply made up of loose *débris*, and A was cased with a thin shell of stone work, as it appeared to be a large place and difficult to fill air-tight, with *débris* only. When the shot was fired, the air was momentarily driven away for some distance on either side, and the chemical processes set up, removed the atmospheric oxygen from the sphere of action; the pressure in the communication against the stoppings was consequently greatly diminished, and the air in the old roads on the inside, under the weight of the column of air in the shaft, forced them out into the communication.

It is now manifest that carbon monoxide could not have been in the Great Seam old roads, nor in the cavity; and it is not difficult to understand how the sensitive Alcohol flame of Stokes' lamp exhibited variations from its appearance in the normal air, when it was placed in a partially confined and small space like the cavity, where the atmospheric oxygen was being consumed by the observers, and carbon dioxide substituted in its place; nor that a similar variation was observed in unventilated roads, especially in the Slyving old road between No. 8 and No. 9 Explosions (Plate I.), as the noxious products of the explosions were diffusing out of this road into the communication, for some time after these lamp tests were made.

Upon referring to Plate I., it will be observed that the cavity and old road, where Mr. Batey places the originating explosion, is some distance outside of the field, which contained the exhibitions of explosive violence, and leaves the disaster entirely unexplained, except upon the hypothesis that carbon monoxide was present in the air that filled the workings at the moment of the explosion, in sufficient quantity to make an explosive mixture with air and coal-dust. Carbon monoxide requires to be mixed with two-and-a-half times its volume of air, to effect its explosive ignition; it therefore represents 28·5 per cent. of the mixture; but Mr. Batey suggested that "4 per cent. to 5 per cent. of carbonic oxide gas in combination with air and coal-dust would form a most explosive mixture, and one very difficult to detect."[1] If there were scientific investigations to sustain that suggestion, the fact would still remain, that if the air contained one-half of one per cent. of carbon monoxide, all the men in the field of disaster must have been poisoned before the explosion occurred; whereas the positions of the bodies show that they were alive immediately before the explosive ignitions.

It has been shown that there was no carbon monoxide in the old workings, and that there could not have been any in the cavity; the suggested sources of the gas therefore fail.

The essential product of the explosive combustion of carbon monoxide is carbon dioxide; but it has been shown that carbon dioxide was not in the products of the explosions that filled the mine; therefore the absence of carbon monoxide in the explosive ignitions, becomes an induction of scientific certainty.

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[1] "Reports upon the Explosion at Timsbury Colliery," p. 8.

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